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Development of a Computer Based Energy Management System

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ABSTRACT

A prototype computer based expert system has been developed to aid energy managers by speeding the energy auditing process and rapidly identifying potential low cost and fast pay-back energy saving investments for a wide range of businesses.

It consists of a generally applicable energy management system based on sound, tried theory and practical experience gained from a number of energy management surveys. These surveys were used to identify key data requirements for the identification of common areas of wastage. The system uses sparse data analysis and the building energy signature model. It produces an entire energy audit and list of economic recommendations for a site based upon minimal input data. This is accomplished by reference to a number of internal databases containing the technical information required, as well as the entire set of algorithms and mathematical routines required for the analyses.

The prototype was tested with a synthetic data set derived from the site surveys and with real data from a large tertiary college and it was found to give credible results in line with those produced by extensive and in-depth manual data-gathering and analysis.

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LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
BEMS, BMS	Building Energy Management System, Building Management System
BMA	British Medical Association
BRE, BRECSU	Building Research Establishment, BRE Conservation Support Unit
BSRIA	Building Services Research Industries Association
CFC	Chlorofluorocarbons
CHP	Combined Heat and Power
CIBSE	Chartered Institute of Building Services Engineers
CPU	Central Processor Unit
EEO	Energy Efficiency Office
ETSU	Energy Technology Support Unit
FCU	Fan Coil Unit
GUI	Graphical User Interface
H&S	Health and Safety
HEP	Hydro Electric Power
KBS	Knowledge Based System
LBRUT	London Borough of Richmond upon Thames
NOx	Nitrous Oxides
NPI	Normalised Performance Indicator
NVQ	National Vocational Qualification
PIR	Passive Infra-Red
PV	Photovoltaic
PWR	Pressurised Water Reactor

RAM	Random Access Memory
RUTC	Richmond upon Thames College
SG	Sundry Gain
SME	Small or medium size enterprise
SPBP	Simple Pay-Back Period
tce, toe	Tonnes of Coal equivalent, Tonnes of Oil equivalent
TDS	Total Dissolved Solids
TSRV	Thermostatic Radiator Valve

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1. INTRODUCTION

Although deregulation has caused a dramatic short term drop in energy prices, demand for energy world-wide is outstripping supply and will continue to do so for the foreseeable future. This, combined with changes to legislation and taxation in response to perceived environmental problems, will drive energy costs up. Businesses which are energy profligate will become un-competitive on both a local and a global scale. Such commercial considerations are likely to have more influence on business than arguments for sustainability based upon less immediate but equally valid environmental concerns.

Despite EU and UK government initiatives to promote energy efficiency, energy management is widely ignored, particularly by smaller businesses. Reasons for this are manifold. In many companies there is a natural reluctance to change, "if it ain't broke don't fix it". Taking on energy management is expected to require capital investment, which may be in short supply, and to incur disruption of existing systems. In addition, energy costs may be considered trivial, often only a few per cent of turnover, and energy management viewed as a distraction from the really important work. Consultants may be viewed with suspicion, while ignorance, the effort required to learn about energy management, and lack of self confidence in an area outside of their original expertise deter people from doing it for themselves.

Given this commercial and technological setting, **the objectives of this work can be summarised as follows:**

1. Evaluation of generally available computer based data management and manipulation tools with respect to their application to the automation of routine energy management tasks.

2. Development of an energy management technique based around sparse data analysis using the building energy signature model.

3. Creation of an automated computer-based expert system designed to aid an energy manager in completing routine energy management tasks in accordance with the energy signature model, producing the full energy audit and a ranked list of recommended low cost fast pay back remedial measures.

The work is intended to provide a system which can be generally applied by energy professionals to identify simple, cheap and effective energy-saving measures, which is in itself cheap to employ and which follows officially published best practice. It is anticipated that such a system would provide substantial benefits in terms of effort, time, and cost savings for energy auditing, and analysis. Investment in energy saving follows a law of diminishing returns. The system described herein is not designed to hunt out every possible saving on a particular site, but to make reasonable estimates of major savings possible on most sites from a relatively small amount of generally applicable data.

2. ENVIRONMENTAL BACKGROUND

2.1 Why Bother With Energy Management?

There are a number of reasons for investing in energy and environmental management:

- Statutory requirements
- Consumption of finite resources
- Population growth
- Freeing of resources for other uses
- Pollution prevention
- Environmental damage due to energy procurement
- Energy security
- Risk reduction
- Financial impact

2.1.1 Statutory Requirements

"Green" legislation is already established and is expanding due to popular opinion and international pressure. Traditionally this tends to trickle down from the countries of Northern Europe and the United States, where conservation legislation is already well in place.

The EC is also forcing legislation in accordance with the EEC Treaty (the primary legislation of the EC, incorporating the Single European Act);-

EEC Treaty article 130

1. Action by the Community shall have the following objectives:

(i) To preserve, protect, and improve the quality of the environment.

(ii) To contribute towards protecting human health.

(iii) To ensure a prudent and rational utilisation of natural resources.

2. Action by the Community relating to the environment shall be based on the principles that preventative action should be taken ... Environmental protection requirements shall be a component of the Community's other policies.

Some other international agreements which have been made and which have affected energy consumption were;-

- **1992 Rio UN Climate Convention**. It was recommended that Greenhouse gas emissions should be stabilised at 1990 levels by 2000.
- **1988 Toronto Protocol**. It was recommended that CO_2 emissions should be reduced to 80% of 1988 levels by 2005.
- **1987 Montreal Convention**. It was recommended that CFC emissions should be cut by 50% by 1995, 85% by 1997, and phased out entirely by 2000.
- **1982 Stockholm Accord** formulated on the reduction of sulphur emissions.

2.1.2 Consumption Of Finite Resources

Various sources give different figures for fuel reserves, but the end result is the same, in the near future our non-renewable fuels are likely to be depleted. In "Energy Management" Paul O'Callaghan estimated that world fossil fuel reserves, i.e. coal, gas, and oil, would be depleted by 2050 if consumption continued at 1986 rates. Oil and gas reserves in particular were calculated to give out well before that point. These dates could not, however, be fixed because of external factors such as the discovery of new reserves and changes in consumption rates.

Even though there may be discovery of new fossil fuel reserves, the total amount on the planet is finite. It is likely that over the past century we have exhausted half the available fossil fuels available and no amount of "market forces" can increase the amount available.

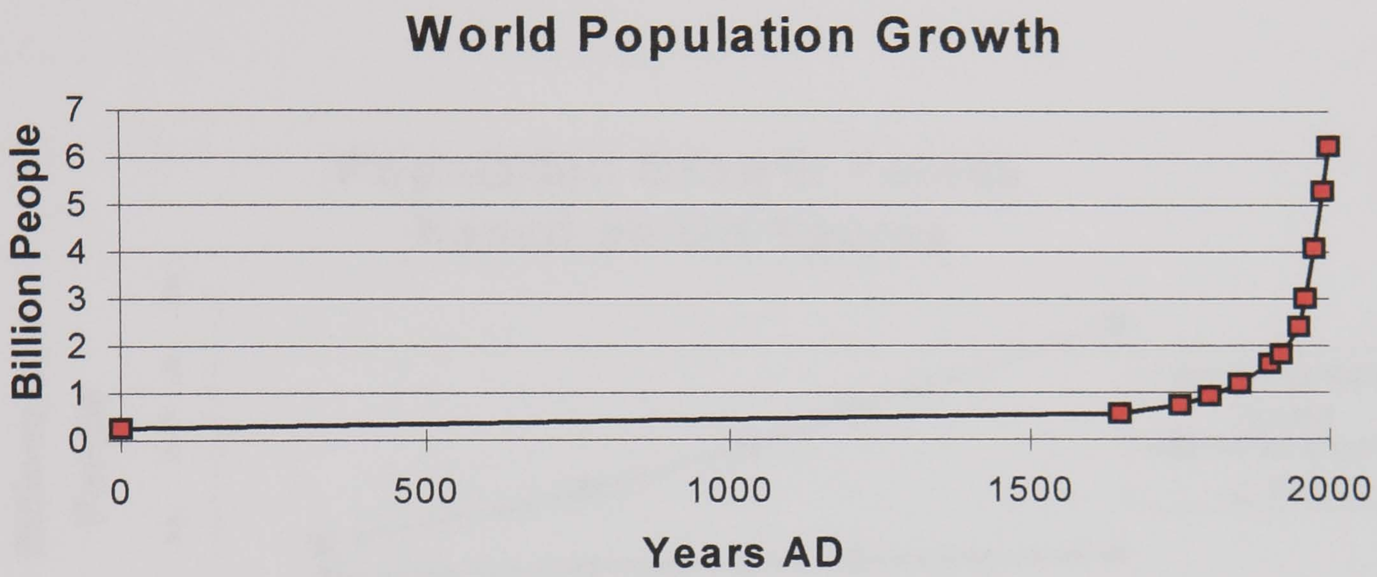
The cost of procuring and using fossil fuels is increasing as the easily exploitable sources and higher quality fuels deplete. Some economists and politicians see this as a good thing because in the short term it makes exploitation of Britain's North Sea oil fields financially viable[1], but, even without considering increased costs to industry and the squandering of past oil revenue to promote a false economic boom, this is not in our long term interest.

Eventually fossil fuel reserves will exhaust, but conservation measures could greatly extend the useful life and buy time for alternatives such as safe nuclear or renewable energy technologies to be developed. Additionally, the reduced energy requirement

[1] Brown W.M. "The Outlook for Future Petroleum Supplies" printed in The Resourceful Earth, Simon JL and Kahn H. (Blackwell 1984).

resulting from conservation measures will be more easily accommodated by renewable energy sources such as tidal, wind, etc., as they are developed.

2.1.3 Population Growth

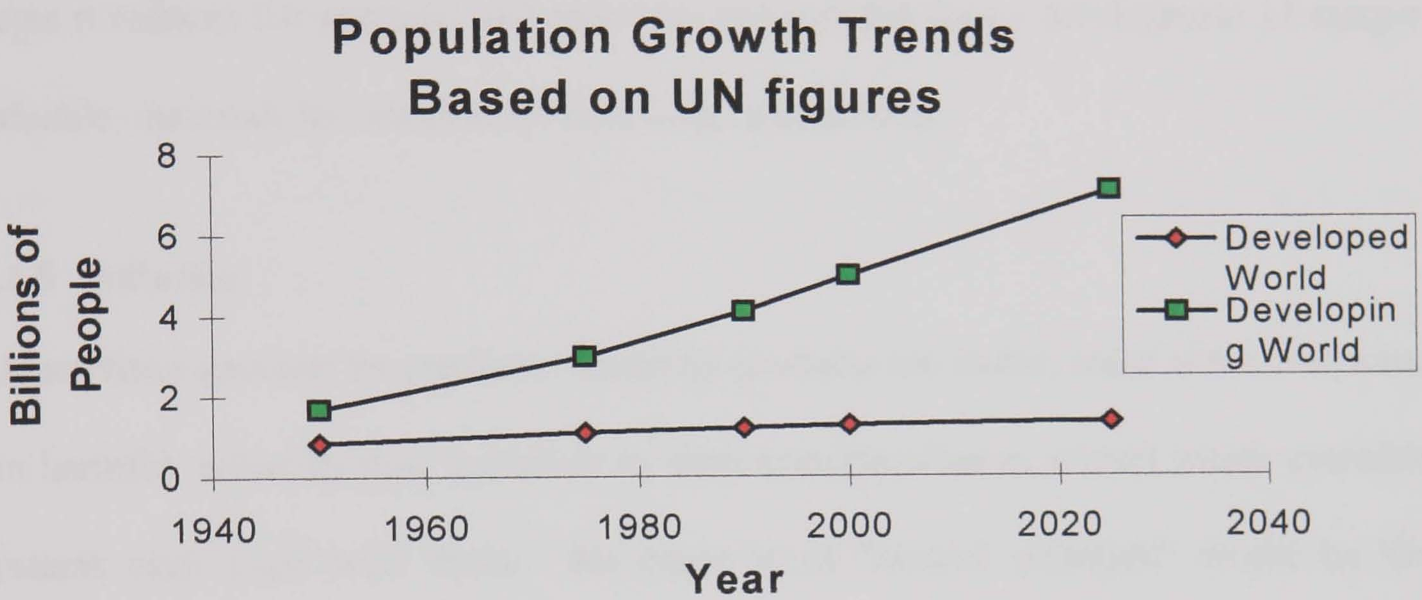


World population growth is slowing, and is likely to stabilise early in the next century, but estimates of the final human population vary from about 6.25 to 12 billion people[1].

If that number of people is to be supported there must drastic improvements in the efficiency with which energy, water, and other resources are used. For purely selfish reasons it is in the developed countries interests to develop and export the necessary technology, since otherwise they will be swamped by other nation's pollution. For example over the decade 1980 to 1990, China increased coal production to 1.1 billion tonnes a year, and was also the world's largest refrigerator manufacturer (i.e. the world's largest producer of CFCs). The Pacific rim countries have decided that their future energy needs can only be economically met with nuclear power. Unless the west can convince such countries that it is cost effective to conserve the environment our own restrictions are useless. It would be prudent for developed countries which have

[1] In 1988 the United Nations predicted a World Population of 8.467 billion people by 2025. World Population Prospects 1988 (United Nations, New York, 1988).

the capacity to develop energy efficient technologies to do so, and then export them to developing countries, where population pressure and economic weakness make investment in developing such technologies a low priority compared with feeding their people and maintaining political stability.



"In the longer term growth in energy demand will be driven by increase in population, of which over 90% will take place in the developing countries. Actual growth rate will depend upon the extent to which populations are able to improve efficiency of end use in energy production and conversion"

- *Derek Davis of the World Energy Council*

2.1.4 Freeing Of Resources

Reduction in demand for hydrocarbons as fuel frees them for other important uses such as lubricants and plastics manufacture.

Some of the uses to which plastics are put are deplorably misconceived, and a graphic example of the folly of political economics simply based on direct financial costs. However polymer science offers unique opportunities in materials development if only we can get away from thinking of plastics as cheap and disposable. If the raw materials from which plastics can be easily manufactured are burnt or thrown away as disposable items it reduces the potential and increases the cost for future development of unique, valuable, materials for which there may be no alternatives.

2.1.5 Pollution

All activities generate by-products. Some by-products are useful, some aren't, and some are harmful, either by their nature or by their concentration at a level where available systems can't cope with them. An example of "natural pollution" would be the occasional washing inshore of the deep sea dynaflagellate botulinus, which produces highly toxic botulin as a metabolic by-product, resulting in substantial environmental impacts[1]. This was the organism responsible for the botulism scare concerning canned fish in the late 1970's and is sometimes described as the "red sea" or "red death" (it has also been deliberately manufactured, along with anthrax, as a biological warfare agent by Iraq, and probably other countries).

Where human activity produces by-products which we can't use, and which by their nature or concentration cause environmental damage, we call it pollution. For example, methane can be produced by decay of organic material in waste sites. If we trap it and

[1] Botulin Toxin has it's defenders, it is injected by cosmetic surgeons, to smooth facial wrinkles by paralysing the underlying muscles!

use it as fuel it is a useful by-product, if it is simply released into the atmosphere it is a greenhouse gas.

It should be born in mind that even if there is no obvious environmental damage there could be some subtle effect taking place.

Wastage has a cost both in production and disposal. According to the US Environmental Protection Agency the United States spent $115 billion on pollution abatement in 1990, this figure is expected to rise to between $171 and $185 billion per annum by the year 2000.

2.1.5.1 Climate Change And The Greenhouse Effect

There is still debate about the existence, cause, and degree of global warming. The greenhouse effect was first proposed by the Swedish chemist Svante Arrhenius in 1896 to account for ice ages, but there is now general consensus amongst environmentalists that increased human activity is giving rise to a greater concentration of "greenhouse gases" in the atmosphere. These gases, primarily water vapour and carbon dioxide but also methane, nitrous oxide, CFCs, and tropospheric ozone, have the property of transmitting short wavelength radiation, such as that radiated by the sun, but absorbing longer wavelength radiation such as that re-emitted from the cooler surface of the earth. It is suggested that the earth's average temperature (currently about 15°C) is rising as a result, and some correlation's have been found of atmospheric CO_2 and methane concentrations against average global temperatures. Deforestation doesn't help, as the trees being destroyed (and burnt) would otherwise help remove CO_2 by photosynthesis. The current wave of concern about global warming was triggered in 1988 by Dr James

Hansen of the Goddard Institute for Space Studies, who stated categorically to a Congressional hearing that a drought then befalling the American mid-west was due to global warming caused by CO_2 from burning fossil fuels.

Predicted results of global warming are changes in rainfall, affecting agriculture, a sea level rise, causing flooding in low lying areas. It is claimed that the desertification in sub-Saharan Africa and flooding in Bangladesh are evidence of this. It has been suggested in a recent BMA report that global warming will result in plagues, as conditions favourable to particular diseases develop in areas where the population have not previously been exposed, and thus have not developed any immunity.

However, there are serious flaws in the Greenhouse Theory, and it is far from proven[1]. Even so, the perceived threat of global warming and political pressure make it likely that some form of carbon taxation will be introduced. This will drive up energy prices and make energy efficiency measures more cost effective.

2.1.5.2 Smog And Acid Rain

Like Global warming, there is a feeling in some quarters that the Green case has been overstated, however there is likely to be more basis for concern though the effects may be less extreme than claimed. Unfortunately, political spin doctoring and the tendency of pressure groups on all sides to misinterpret data in support of their campaigns has confused the issue.

Combustion of fossil fuels produces SO_2 and NOx gases as waste by-products. These combine with atmospheric water vapour to form acids, the process is enhanced by sunlight to produce photochemical smog. Particulate matter in the air, often a result of fuel combustion, also aids nucleation of smogs. Particulates, SO_2 and NOx are typically generated by heavy diesels and older coal burning installations, though poorly tuned cars and even grilled foods are said to contribute to the problem (in the summer of 1996 it was claimed that more smog was caused by barbecues than by buses and cars in Los Angeles, but less than that from lorries). The Australian National Research Organisation has even produced evidence that many of the volatile organic compounds responsible for photo-chemical smogs are naturally released in large quantities by vegetation, particularly grasslands, but the eucalyptus oil haze over the Blue Mountains is seen as picturesque despite it's visual and chemical similarity to the haze over major cities[2].

Such smog is notable over cities, famously Los Angeles, where traffic fumes are a major contributor. In Britain the 1956 Clean Air Act was passed as a result of 5 days of London smog which killed 4,000 people in 1952. Even in 1990 the American Lung Association estimated that disease due to air pollution cost the USA between $1 billion and $10 billion per year, depending on whose figures you believe.

Acid Rain occurs when acid fumes dissolve in clouds and then precipitates as rain, often many kilometres from the source. This makes it difficult to pin down responsibility on the polluter.

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[1] Emsley J. The Global Warming Debate. (European Science and Environmental Forum 1996).

[2] Could this be related to the reported increased incidence of Asthma? It may even be part of the plants defence or pollination mechanism. Certain trees release chemicals resembling green-fly alarm pheromones when attacked by aphids, other plants release chemicals to attract insects for pollination. Presumably cereal crops and oil-seed rape release such chemicals, and the amount released will increase considerably during harvesting.

The full effects of acidification are still unclear, but there is evidence that it damages trees and other flora, and that acidified lakes give lower fish yields[1]. It also seems likely that acidification of water and soil disrupts the nitrogen cycle, the long term effect of this is not yet known but unlikely to be beneficial. One view of the effect of acid rain is that tree damage may be linked to increased leaching of nutrients such as calcium, magnesium, and potassium, from already poor soils, and that these nutrients collecting in normally fairly nutrient poor lakes shifts their ecological balance against the existing predominant species. Toxic substances such as metals, which may reduce the ability of fish to take up oxygen, are also released into the water by the acidified runoff. At the same time that nutrients are being leached out, the soil's biological activity is reduced, so that the decomposition rate of organic debris is reduced, slowing the release of nutrients into the soil. Aluminium mobilisation due to acidification also has toxic effects. Direct damage to trees may be due to formation of bisulphates and nitrites in the leaves due to absorption of acids. Bisulphates reduce photosynthesis and nitrites are toxic to plant cells. The action of leaf stoma through which the acids are absorbed is impaired, enhancing water loss in dry weather and reducing resistance to frost damage. It is also possible that the action of some pests is enhanced by acidification.

As well as falling as rain, acidified clouds may damage trees on any high ground which projects into the cloud base, and dry deposition of acid fume may cause environmental damage nearer the source. Heavy metals may also be deposited as a toxic by-product of combustion.

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[1] DOE. The Effects of Acid Deposition on the Terrestrial Environment. (HMSO 1988).

Acidification not only harms natural systems it also damages man-made objects such as buildings, statuary, etc. In this way, as well as in damage to agriculture, it causes an identifiable financial cost as well as the environmental cost.

2.1.5.3 Nuclear

Nuclear power is the only non-renewable energy resource for which there seems to be a long term possibility, but it has its own particular hazards.

Most public concern has focused on fears of accidents occurring at a nuclear power station. Recent incidents in the former soviet union re-enforce that disquiet. The Chernobyl incident in particular has shown the potential for disaster, with over 10,000 square kilometres contaminated to unsafe levels by fall-out, and a further 21,00 square kilometres contaminated to a level of between 5 and 15 curies / km^2. Pockets of dangerous contamination were found up to 480 km north and 320 km south of the plant. Some 1.25 million people have been affected by the incident, and 627,00 are under permanent medical observation. It should be pointed out that the "RBMK" reactor design used at Chernobyl was recognised by western countries as being inherently unsafe, and Britain decided that it was too unsafe to develop as long ago as 1947.

Nuclear reactors of various designs, some safer than others, are in use around the world. Although more efficient power from nuclear fusion may be just around the corner at present nuclear-electric technology is based upon atomic fission. Some by-products of this can be recycled, but large amounts of high and low level radioactive material simply have to be sealed up and safely stored, probably for thousands of years.

The main hazard from such wastes is ionising radiation, but some materials are also chemically toxic. Who, speaking today, can guarantee the security of such dumps over the next thousand years? There is already concern about increased incidence of cancers around nuclear plants, and the possibility of seepage into groundwater or the sea. At the Idaho National Engineering Laboratory, site of the world's first commercial nuclear power station and a waste storage facility, plutonium has leaked into the aquifer which supplies southern Idaho.

The problems of nuclear waste storage have been examined in the US government study of long term security at its Carlsbad storage site. Here the idea is that over time the salt would fuse around highly radioactive waste material buried deep underground, so sealing it in. Even so there is a worry that in the future there may be wars and other political or social upheavals during which the knowledge of what is buried there is lost. If that happened it is conceivable that high level radioactive material might be released by mining operations or some similar activity at some time in the future. The current debate is whether it would be safer to clearly mark the site with warnings, or whether such artefacts might encourage people to excavate the site. After all, the knowledge of what Egyptian hieroglyphs meant was lost for over a thousand years, in another millennium people might not be able to read English and electronic media become obsolete within a decade (There are floptical computer discs less than 5 years old from which the data can no longer retrieved because they have been rendered obsolete by better storage devices, so it is impossible to buy a drive for them any more).

Russia seems to have no strategy for dealing with nuclear waste, and is notorious for releases into waterways and direct injection of high level liquid waste into the ground, where it can infiltrate into the groundwater and so be released into waterways. The Russian line is that the waste is injected into layers of shale and clay 300 to 700 metres down, where it is trapped. US experts disagree and say that it is being flushed to the surface and dissipated to rivers and lakes by groundwater. In Britain 100 m^3 of such high level liquid waste is produced annually, and currently stored in cooled tanks at Sellafield.

Even if fusion reactors are developed they are still likely to produce such waste, which will have to be safely stored. One promising innovation being developed by CERN is a reactor which maintains fission by bombarding the fuel with neutrons generated from a particle accelerator, so accelerating the decay of reactive material. This started out as an idea for disposing of radioactive waste by decaying it to a safe level, but has since developed into an inherently safe reactor design, which only produces about 1% of the waste produced by a conventional fission reactor. The technology is all in existence, but there has been little funding world-wide because such a reactor can not be used to produce fissile material for military use. However, Charles Bowman at Los Alamos hopes to have a prototype up and running by 2005 if funding is forthcoming, working in partnership with Stanford University[1].

2.1.6 Reduced Environmental Damage Due To Energy Procurement

Conservation measures reduce the environmental, energy and financial costs of energy resource acquisition, production, and distribution. About 20% of the energy content of Oil derived fuels is used in their procurement, refinement, and transport to the end user.

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[1] Key people: Los Alamos - Edward A Heighway and Charles Bowman, CERN - Carlo Rubbia. Discussed at the Emerson Electrical Environmental seminars in Angouleme, France, 1994.

Coal only requires about 5% of its energy content to mine, process, and transport, if distributed as Coal gas this rises to 28%. Electricity fares worst, with typically 76% of the primary fuel energy being lost in its generation and distribution. About 60 - 80% of the fossil fuel energy used in a thermal power station never reaches the end user, depending on the fuel and the age, size, and design of the power station. Nuclear power generation is about 35% efficient, and HEP about 70%[1]. The financial inefficiency is less significant since the consumer pays more per unit of energy than the producer, and the costs can always be pushed onto the consumer while profits are hidden, e.g. cost shifting by petrol suppliers.

2.1.6.1 Acquisition

Procuring an energy resource has an environmental impact, whether its harnessing wind or water power or digging coal or uranium from the ground. The impact may be large or small, allowed for or unforeseen.

Mining, drilling, etc., have visible effects, but damming a river can disrupt its ecology by preventing fish migration, and erecting a wind-farm may upset the neighbours. Then again, the equipment used has an environmental cost in its manufacture, and even manpower has to be clothed, housed, fed, etc.

2.1.6.2 Transportation

It takes energy to transport fuel and it generates pollution. In addition, the hardware necessary, be it lorries, pipelines, cables, whatever, has its own energy and financial

[1] Source: Boustead and Hancock, Handbook of Industrial Energy Analysis. This book also contains useful information on energy requirements for various industrial processes and materials.

cost, as does the manpower to run it. In some cases the cost of transportation from a remote area makes exploitation of a resource uneconomic.

2.1.6.3 Accidents

Throughout the chain from source to consumer there is the possibility of accidents which may cause environmental damage, with resulting costs in energy, money, and often human life. The most obvious of these are the major oils spills such as Exxon Valdez[1].

2.1.7 Energy Security

The British and European economies are tied to energy availability and costs, and will remain so for the foreseeable future.

If present trends continue, by 2020 over 2/3 of the worlds oil needs will be supplied from the middle east. The political instability of the region and rise of anti-west Islamic fundamentalism make this an insecure source of supply (as shown by the Gulf war in the 90's and the closure of the Suez canal and raising of oil prices in the 70's), similar problems face the oil fields of the former Soviet Union[2]. Another oil producer, Nigeria, is less than stable, with a succession of military dictatorships and the recent massacres in Ogoni Land.

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[1] The Valdez clean up is said by many to have done more damage than the oil. Dames and Moore wanted to use bio-remediation, but were refused permission by the governor of Alaska because it was an uncertified technology. Instead the US government insisted on steam cleaning of the beaches, which killed everything. The untreated areas recovered. Source - Rory Nagle, Senior Remediation Engineer, Dames and Moore.

[2] In her moving account of the war in Chechnya, Crying Wolf (Picador 1998), Vanora Bennett says that one of the key factors leading to war was control of oil from the Caspian oil fields. Similar interests are said to have destabilised other parts of the former Soviet Union, such as Azebaijan, and have been at the root of the civil war in Georgia.

Any energy conservation measures taken which reduce our dependence on oil imports and large buffer stocks will help reduce our vulnerability.

As well as reducing the potential for political/economic blackmail, reduced demand should, in a free market, reduce the price we have to pay for oil imports.

Another aspect of security is the risk of war and terrorism. During the Iran-Iraq war both sides attacked ships at their opponents oil terminals to deny them the use of oil as an economic resource.

Energy resources can be attacked with the intention of causing environmental damage, rather than simply denying the use of the resource. Saddam's ignition of Kuwait's oil fields is an example, and recent years saw an IRA attempt to bomb gas storage tanks in an urban area. There has long been concern about the possibility of terrorist attacks on nuclear installations, or theft of material suitable for nuclear weapons[1].

2.1.8 Risk Reduction

Reduced demand due to conservation measures reduces the risk associated with energy production, distribution, and utilisation.

> *"An economist looking at the risks to human health imposed by energy producing technology would note two salient points:*
>
> *(i) The actors causing the increased risk (the risk imposers) do not, in general, have to pay for the risks they cause.*

[1] as Mossad, the Israeli secret service, is alleged to have done.

(ii) The actors on whom the increased risks fall (the risk receivers) do not, in general, have a choice about whether to accept the risks or not."

- Nigel Evans and Chris Hope, Nuclear Power, Cambridge University Press 1984.

Evans and Hope have established risk indices for coal, HEP, large scale wind, small scale wind, nuclear, and energy conservation technologies in respect of deaths per Giga-Watt year of electricity (1 death = 6000 person days of incapacity). They then apply different weightings to those indices to rate the risks of each technology from different viewpoints. Using 3 of 4 weighting schemes conservation was the safest option, the 4th had conservation coming third after nuclear and hydroelectric (this is the weighting method used by the nuclear industry)[1].

The risk associated with conservation is due to the deaths and injuries likely to be sustained manufacturing materials, fitting conservation measures (falling from roofs, etc.), accidents to third parties, etc. In view of the spread of estimates of such risks, likelihood that conservation measures would be carried out as part of other work, and better hazard awareness with increased familiarity, it is likely that in practice conservation measures would score significantly better.

[1] Note: The risk of death due to a nuclear accident is often quoted as being less than being killed by a meteorite. This is based upon the theory that at various times in prehistory terrestrial life was substantially reduced by giant meteor impacts, so misleading. Using similar logic one could say that since there is always a small possibility of a nuclear accident, given enough time we are certain to be killed by one. Of course, the whole thing about probability is that its just as likely to happen tomorrow as in a thousand years time.

2.1.9 Financial

Unfortunately all of the preceding arguments tend to become "someone else's problem". The most potent argument for investment in energy management is that it reduces overall costs.

An individual or business investing in energy conservation will see a reduction in energy bills which soon repays the capital expenditure. Similarly, a country which can increase it's energy efficiency will reduce it's imports and gain an economic advantage.

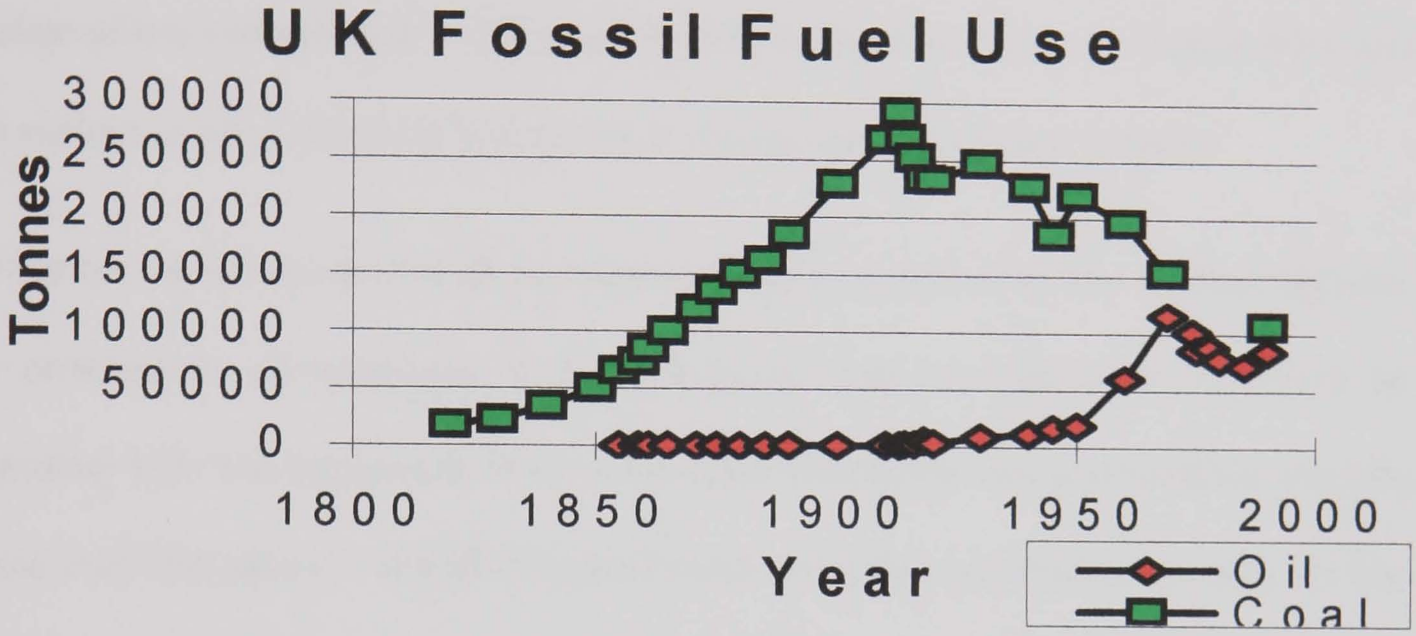
Energy inefficiency also has a cost to individuals and to our society.

> *25 - 50,000 Britons (mainly OAPs) die each winter because they can't afford to heat their homes. VAT on domestic fuel was expected to add 10,000 per year to that number.- World in Action, ITV, Oct 18th 1993.*

The figures are debatable, they're probably based upon the excess of winter over summer mortality figures which runs around 50,000. Apologists would say that actual deaths from hypothermia are only around 1000 per year (*source- House of Commons Debates, 13th Feb 1981, col. 443*), and that there are simply more diseases like flu around during winter which might finish off an old person. Alternatively one could argue that someone who has been weakened by cold is likely to be more susceptible to disease.

Whatever one's position, the 1972 National Survey of Hypothermia and Heating found that between January and March 1972, which was a mild winter, 700,000 old people suffered from hypothermia in Britain. Demographic changes, reduction in the value of pensions, and changes in social security spending, are likely to give a much higher contemporary figure.

2.2 Future Energy Resources



In 1990 Oil was the worlds major fuel, supplying about 40% of world energy, Coal supplied 30%, Natural gas 20%, Hydropower 7%, and Nuclear 5% (all figures approximate due to differences in data from different sources). Fossil fuel supplies are finite and competition for them will increase as developing countries establish manufacturing economies and enter what Naohiro Amaya of Japan's MITI terms "The Oil Culture". In terms of proven reserves, Western Europe had an R/P ratio of 12 years for oil, 34 years for gas, and 219 years for coal[1]. Based upon a 1987 datum and consumption rates, the UK indigenous oil reserve would have been depleted by 1996 if Britain had not been able to import additional fuel[2].

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[1] World Resources 1990-1991, World Resources Institute, Oxford University Press 1990.

[2] Paul O'Callaghan, based upon BP Statistical review of World Energy 1988, BP, 1988.

Despite development of "clean coal" and combined cycle gas-based CHP generation, it is likely that the UK will come to depend upon renewable and nuclear resources to meet its future energy needs, and as these technologies develop hydrocarbons will become more valued as resources for the complex polymers, lubricants, solvents, etc., necessary for high technology. Due to the hazards and long-term waste problems associated with nuclear power generation it would be preferable to maximise the use of renewables, and use nuclear or non-renewable generation to top-up capacity to meet demand.

Britain has useful amounts of all renewable energy resources available for development. To promote the development of Nuclear power and renewables an 11% levy on electricity bills was imposed in 1991 to subsidise alternative energy generation, the Non Fossil Fuel Obligation[1]. The NFFO raised about £1 Billion per annum, but only 2% was initially allocated to renewable energy projects. The share allocated to renewables was gradually increased, with nuclear power only receiving £731 M of the £844 M raised by the NFFO in the year 1996/97[2]. In 1995 nuclear power was privatised, and to promote a European free market in nuclear power a 1998 deadline was set after which nuclear power generation projects would no longer be subsidised by the NFFO, though renewable energy projects would continue to be supported with the intention of developing a Declared Net Capacity of 1500 MW by the year 2000.

Now, in 1998, the levy is only 0.9%[3], and none of this goes to nuclear power.

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[1] Renewable Energy. Godfrey Boyle, Open University / Oxford University Press 1998.

[2] Derek Taylor of the Open University, speaking at Richmond upon Thames College in 1997.

[3] Mike Shilstone, 14th December 1998.

2.2.1 Energy Conservation

Energy conservation offers many benefits, not least of which is that the cost of energy conservation measures is much less than the cost of generator construction to produce an equivalent amount of usable energy. There is also a reduction in distribution cost. In the UK power lines lose 3% per 100 miles, resulting in an average distribution loss of 9.74%[1], it is also estimated that about 10% of oil energy is used in the transportation of oil from production site to end user[2].

The potential for energy conservation is also very large at both the engineering and the user level. Product design affects energy consumption. A modern Swedish house uses only 10% of the energy of the average American house, despite having generally worse climatic conditions. The average American car at the time of the energy crisis in 1973 had a fuel consumption of 13 miles per gallon, 20 years, and a many fold increase in fuel cost, later they still only averaged around 20 mpg, while European cars such as the Citroen AX10 managed up to 65 mpg. In 1990's Britain, for equivalent performances, low energy lighting used a fifth of the power required for conventional lamps, refrigerators 30%, washing machines 50%, and televisions 25%, i.e., even with no change in lifestyle, consumer product engineering could make a large impact[3]. Higher quality products with longer life expectancy, upgradability, etc., also tend to reduce manufacturing energy consumption overall.

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[1] Original reference mislaid, however the Open University T103 Energy module (1993) gives a total distribution loss of 8.3%, and in Electrical Energy Laithwaite gives the transmission loss in power lines as 2.4% .

[2] O'Callaghan. Energy Management.

[3] Green Design Exhibition. The Design Centre, London.

Unfortunately, the generally higher initial cost of low energy products creates opposition in marketing them. The most environmentally friendly development in car design has been front-wheel drive, which made lighter, cheaper cars practical. Other innovations such as lean-burn engines, ceramic diesel engines, and continuously variable transmissions, have not reached the market yet because of their likely development and manufacturing costs. In theory improved engine and transmission design could reduce fuel consumption by 75%, with additional gains possible from lightweight materials and streamlining. In contrast, catalytic converters have been pushed through because there was a profit to be made from them, despite the fact that they reduce a cars efficiency by about 10% and the unleaded fuels needed for them arguably produce more harmful waste products than leaded fuels.

Compact fluorescent bulbs have failed to take off in the UK domestic market due to the high initial cost, despite lower lifetime cost. In the US some electricity suppliers found it cost effective to replace customers GLS bulbs with compact fluorescents free of charge in order to avoid increasing generating capacity. In Britain, Friends of the Earth estimated that if each household replaced one GLS bulb with a compact fluorescent it would save the energy equivalent of a proposed nuclear generator at Sizewell, and be far cheaper.

3. ENERGY MANAGEMENT BACKGROUND

3.1 The Current State of Energy Management in Britain

Despite National Government and European Union initiatives, Energy Management is not widely practised in the UK, and where it is, it's often ineffective. There are a number of reasons for this, but the root cause is that energy is still generally perceived as a cheap and plentiful resource. This impression has been reinforced by the recent deregulation of energy utilities, with the resulting 50% drop in energy prices as new companies vie for market share. According to the DTI's model of the energy economy, for every ten per cent fall in energy prices long term total energy demand rises by four per cent. By July 1996, deregulation of utilities had resulted in a 4.2 % increase in electricity use and 22 % increase in gas consumption. These increases equate to an increase in energy consumption of 3.5 terawatt hours. However, prices are likely to rise as the market stabilises.

In addition, energy management is widely considered to be "un-sexy", of low status, and much too likely to get your hands dirty. To quote the Energy Efficiency Office :

> *"Typically, appeals to control energy consumption do not directly motivate most managers or end users. Most senior managers in an organisation are not immediately concerned with conserving energy. Their main priorities are for the organisation's survival, its efficiency or profitability, and their own professional development."*
>
> - *Best Practice Programme General Information Report No. 12 "Aspects of Energy Management".*

The EEO estimate that 20% of the energy used in buildings could be saved by simple conservation measures and basic energy management.

According to surveys carried out by the Building Research Establishment Conservation Support Unit of organisations with an energy spend greater than £500,000 per annum (i.e. those with a strong incentive to manage energy effectively):

- At least half treat energy management as a marginal activity.
- Only one third believed that they had effective management of energy in at least three quarters of their buildings.
- Less than 10% had been able to implement monitoring and targeting systems which worked properly.
- What energy related information they do have available is poorly integrated into their management systems.
- Organisations with many small premises have special problems getting reliable meter readings of energy consumption.

Another report by the Corporate Commitment Campaign for the DTI states that only half of all medium to large companies practice any form of energy management.

The obvious conclusion is that the majority of businesses don't care about energy conservation. Because they don't care they are unlikely to invest in training, manpower, or capital investment to conserve energy. An example of this lack of interest is the pharmaceutical giant Glaxo. Wellcome Pharmaceuticals in Kent had a well established and effective energy management system, with computerised

Monitoring & Targeting and weekly calculation of Degree Days based on actual temperatures measured on site to give a continuous analysis of energy use cost centre by cost centre. Wellcome was bought up by Glaxo and the energy management system was abandoned because it was seen by Glaxo as a diversion from the business of producing pharmaceuticals. This was despite a very significant energy spend of around £ ½ M per annum[1].

There are various tactics to promote interest in energy conservation to Industry, for example:

- Legislation - force companies to meet targets.
- Green PR - emphasise the marketing benefits of an eco-friendly image.
- Support - make it easier for them by providing technical advice, research funding, etc.

Most government action has been in the area of support, through agencies like BRE and ETSU. Legislation has tended to concentrate on the possibly harmful by-products of energy consumption, though new building standards and the proposed carbon tax directly target energy wastage. There has been some overlap between support and PR in that energy saving initiatives can be publicised and so promote an environmentally concerned image for the company. A good public image may then help the company in promoting its products, reducing opposition to development, or even recruiting high calibre, well motivated, staff. Legislation and regulation by setting standards helps

[1] Information direct from Ralph Wilby at Glaxo-Wellcome.

support the development of energy management systems by giving people a framework and targets to aim for.

Green PR may be losing its effect. The 1995/96 government advertising campaign 'Wasting Energy Costs the Earth' resulted in only 12,000 enquiries from the public, at a cost of over £1.3 million. Since there is usually very little action taken as a result of these enquiries, the campaign is considered to have flopped. However, there is still seen to be a competitive advantage in having an environmentally friendly image on a European level.

3.1.1 BS7750:1992 Specification for Environmental Management Systems

BS7750 (which has now been superseded by the similar ISO9000 series) was derived from BS5750, the standard for Quality Systems. BS7750 laid down a standard for environmental management, and much of it is directly applicable to energy management. Section 4 of the standard lays out requirements for environmental management systems in the areas of corporate policy, organisation, and personnel, environmental effects, documentation, control, auditing, and reviews. These are further developed in Annex A of BS7750. BS7750 provides a useful and concise framework for anyone wanting to set up an environmental management system, and is easily adapted to suit energy management. Since management of energy is a part of any good environmental management system, this is no great surprise.

3.1.2 The 1996 Standards for Managing Energy

In 1996 the Institute of Energy and Department of Trade and Industry launched the National Standards for Managing Energy as a basis for accrediting energy management and energy management training. The standards were developed by an organisation called the Management Charter Initiative, and are largely derived from the existing Management Standard, which MCI had also developed.

The standards identify three *key roles*, which are sub divided into *units of competence*, and further broken down into *elements of competence*, all of which are supposed to support the *key purpose* of "ensuring the effective management of energy resources to meet the organisation's objectives". To support any application for recognition under the standards there are *evidence requirements* related to the elements of competence, which can be provided as various forms of evidence, such as reports written by the applicant or statements by employers, etc.

The standards as they stand today seem to have been prepared by people with a business studies background but little or no practical experience of energy management. The associated National Vocational Qualifications (NVQ) are largely based on paperwork generated, with no apparent technical control to measure the effectiveness of any action taken. It's as if the ability of a surgeon was judged on how many requisition forms he'd filled in for bandages, rather than how many patients had survived his operations. The supporting evidence for an NVQ can be in the form of Observable Activity, Product Evaluation, or Knowledge and Understanding. Observable Activity requires that an assessor spends time with the candidate watching them work, this would be expensive and is unlikely to happen except where the assessor works for the same organisation. Knowledge and Understanding is a question and answer based fall back for cases where the candidate cannot provide supporting paperwork. By far the cheapest and most likely assessment method will be 'Product Evaluation', i.e., checking that the necessary paperwork has been done. Quality control for the standard is uncertain, with the checklists provided for assessment so vague that they are worthless to anyone real-life situation, and as the scheme expands the assessors could be less than expert in the subject they are examining because they simply have to verify that the relevant paperwork has been done. At the moment (1998) the University of Oxford Delegacy for Local Examinations working with the Institute of Energy are in the only ones delivering the NVQ, so there is fairly tight control. As the scheme expands to bring in funding-hungry local colleges, and the number of assessors needed grows, this quality control may not be maintained.

The qualification required to assess someone's skill and experience in energy management is not a lifetime working on energy management, but:

- possession of an NVQ as an assessor, which does not seem to be specific to any particular subject but simply makes sure you know how to fill in the paperwork correctly, and
- "occupational competence", again open to interpretation and abuse.

Although Louise Collins at the Institute of Energy asserts[1] that Management of Energy NVQ assessors will have to be energy management professionals, this has not necessarily been the way things worked out in practice with other engineering NVQs.

It could be argued that the Standards are only part of a package of initiatives, such as the Best Practice Programme, which are available for people to draw on. In many cases

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[1] In conversations and correspondence with the author.

there will be either no attempt to find these other resources, or if they are found the amount of work necessary to read and cross reference them in order to create an effective energy management system will be more than the average site manager will want to bother with. If delegated to someone without relevant training or experience there is little chance of anything worthwhile resulting, though the necessary exercises may be completed on paper.

On a more positive note, the standards do promote awareness of energy management as an important role within a company. This may generate interest at the top which will stimulate action at lower levels ("If the boss thinks it's important maybe I'd better do something about it"). Funding for training, better maintenance, and the use of external energy consultants may be made available, or at least the people responsible for energy management may have more leverage to get things done.

In the area of education and training, the standards at least provide a skeleton around which supporting materials and training courses can be developed. The University of the West of England has responded to this need by developing a distance learning course on Energy Management, with help from IoE, Seeboard, EEO, and the EU D.G.17. A similar part-time course[1] ran successfully from 1991 to 1996 at Richmond upon Thames College but stalled for lack of funding.

3.1.3 The Best Practice Programme

The Best Practice Programme provides technical information and support to promote energy efficiency. As well as reporting on specific energy saving projects undertaken

[1] Taught by George Georgiou, Rod Gross, and Liam Nagle.

by various organisations, it provides guides and handbooks of generally applicable energy management strategies. UK and EU sponsorship for energy efficiency research and pilot projects can also be made available through the Best Practice Programme.

SAVE and CADDET are international programmes for promoting energy efficiency, both are administered by ETSU within the UK, and can tie in with the Best Practice Programme. SAVE funds new energy saving developments, while CADDET pays for dissemination of proven technologies. SAVE is an EU initiative, CADDET is run by the International Energy Agency and OECD, and includes non European partners like the US, Australia, New Zealand, Canada, Korea, and Japan

3.1.4 Making a Corporate Commitment

Making a corporate commitment and the energy efficiency accreditation scheme are attempts to involve non-technical higher management in energy efficiency. They are a result of the recognition that without the active interest of senior management the technical support offered by Best Practice will be ignored by most organisations. By integrating energy, and now environmental, management into the company's management and quality control structures it is hoped that the subject will be taken seriously by those with the authority and influence to make changes.

3.1.5 The Energy Management Matrix

Level	Energy Policy	Organising	Motivation	Information Systems	Marketing	Investment
4	Energy policy, action plan and regular review have commitment of top management as part of an environmental strategy	Energy management fully integrated into management structure. Clear delegation of responsibility for energy consumption	Formal and informal channels of communication regularly exploited by energy manager and energy staff at all levels	Comprehensive system sets targets, monitors consumption, identifies faults, quantifies savings and provides budget tracking	Marketing the value of energy efficiency and the performance of energy management both within the organisation and outside it	Positive discrimination in favour of 'green' schemes with detailed investment appraisal of all new build and refurbishment opportunities
3	Formal energy policy, but no active commitment from top management	Energy manager accountable to energy committee representing all users, chaired by a member of the managing board	Energy committee used as main channel together with direct contact with major users	M&T reports for individual premises based on sub-metering, but savings not reported effectively to users	Programme of staff awareness and regular publicity campaigns	Same pay back employed as for all other investment
2	Unadopted energy policy set by energy manager or senior departmental manager	Energy manager in post, reporting to ad-hoc committee, but line management and authority are unclear	Contact with major users through ad hoc committee chaired by senior departmental manager	Monitoring and targeting reports based on supply meter data. Energy unit has ad hoc involvement in budget setting	Some ad hoc staff awareness training	Investment using short term pay back criteria only
1	An unwritten set of guidelines	Energy management the part time responsibility of someone with only limited authority or influence	Informal contacts between engineer and a few users	Cost reporting based on invoice data. Engineer compiles reports for internal use within technical department	Informal contacts used to promote energy efficiency	Only low cost measures taken
0	No explicit policy	No energy management or any formal delegation of responsibility for energy consumption	No contact with users	No information system. No accounting for energy consumption	No promotion of energy efficiency	No investment in increasing energy efficiency in premises

The inaccuracy of predictive energy management has caused some disillusion. An alternative approach has been developed at BRE which accepts that the system in most businesses has too many unknown variables and is too dependant on human actions for simple prescriptive guidelines. It recognises that the people on site are the ones who will know most about what is going on, and rather than over-ruling them from outside it attempts to influence the business to progressively bring about organisational changes which promote energy efficiency. Rather than delegating energy management to external consultants who have only a casual acquaintance with the business, it becomes integrated into the everyday management structure, and is run by people who have an intimate knowledge of the company. It is more strategic than tactical, the underlying philosophy is that rather than an outside expert saying "Do X, Y, and Z, and it'll save you some money", you let capable insiders loose with the brief, within general guidelines, to "Look for ways we can save money by saving energy, then make it happen". This approach was so successful for Dow-Corning that it span off into a money making lighting controls and BEMS subsidiary. This approach relies on top management doing more than paying lip service for success, but by giving the Best Practice stamp of approval it can provide leverage for an energy manager to influence change.

Although it is intended as a guide for companies to develop energy management, in many ways it is more a system of classification for the degree of importance placed on energy management by a company. It reflects the structures and systems that companies adopt for managing energy, but this tabular classification clarifies where the company's organisation is in relation to it's aims. By asking staff in various parts of the organisation to independently plot their impression of the company's performance on the matrix, an objective view can be built up, and problem areas identified.

3.1.6 Total Quality Management

The current trend in British and American management philosophy is Total Quality Management, as enshrined in ISO 9000 and it's derivatives. Interestingly it springs from an 8 week course given in 1950 to 340 Japanese engineers, researchers, and plant managers by the American W. Edward Deming. This is credited with turning round the Japanese industrial economy, the West has taken 40 years to catch on.

TQM aims to get the whole workforce dedicated to satisfying the customer. This may or may not happen successfully in a particular case, but what ISO 9000 does stress is the need for companies to adopt an holistic approach to their business, and set it out in a clearly documented Quality Management System.

Key features of a TQM system form the following hierarchy :

1. **Policy** - **Why** things should be done, and **What** will be done.
2. **Procedures** - **Who** will do it, **When**, and **Where**.
3. **Work Instructions** - **How** it will be done.
4. **Records** - **Evidence** that it has been done.

Documentary evidence of such a system is required by ISO 9000.

Businesses with poor energy management usually fail to meet any of the requirements of the above hierarchy. Widespread adoption of TQM should incidentally result in better energy and environmental management. The four requirements of ISO 9000 provide a good basis for any company wishing to implement an energy and environmental policy.

If ISO 9000 gets senior management to attach importance to energy management it should make life easier for the energy manager. To quote the Energy Manager's Workbook "If people at the top in management aren't behind you, energy management and energy efficiency projects will fail" - because no one else will take it seriously either.

Developing individual environmental policies is outside of the scope of this programme, but it should try and nudge people in that direction.

3.2 Building Energy Management

3.2.1 The Energy Balance

For a steady state (i.e. constant temperatures) all energy going into a building must also be leaving it at the same rate, but not necessarily in the same form.

Inputs (Gains) are typically due to space heating, hot water, electrical equipment, solar gains, human beings, etc.

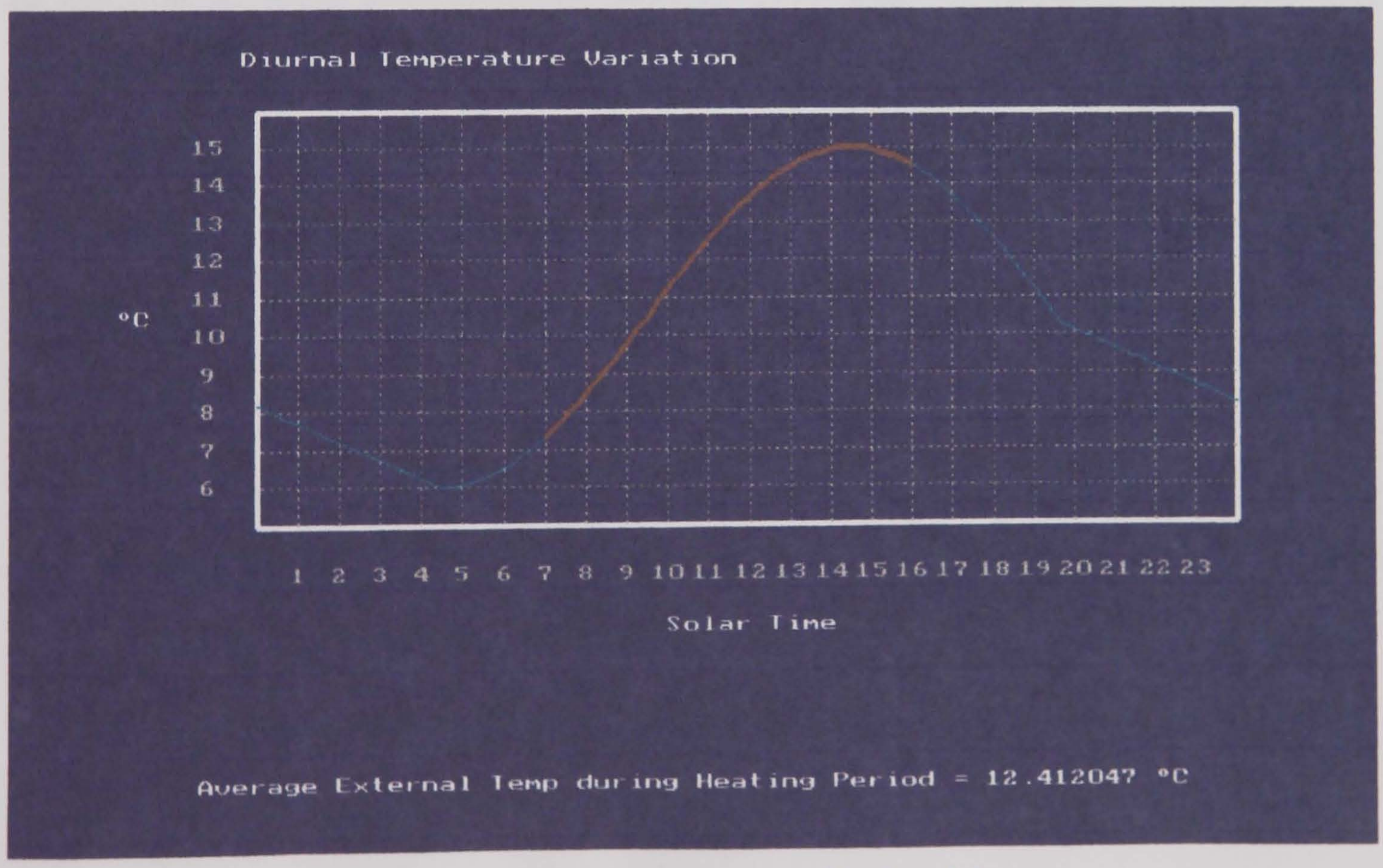
Outputs (Losses) are due to conduction through the building material, draughts, waste hot water to drains, deliberate heat dumping, etc.

The various components of the building structure act as impedances to heat flow, and these can be used to calculate the overall resistance of the building to heat loss. For heat to flow through these impedances there has to be a potential difference between the inside and outside of the building, and this is provided by the temperature difference between inside and outside.

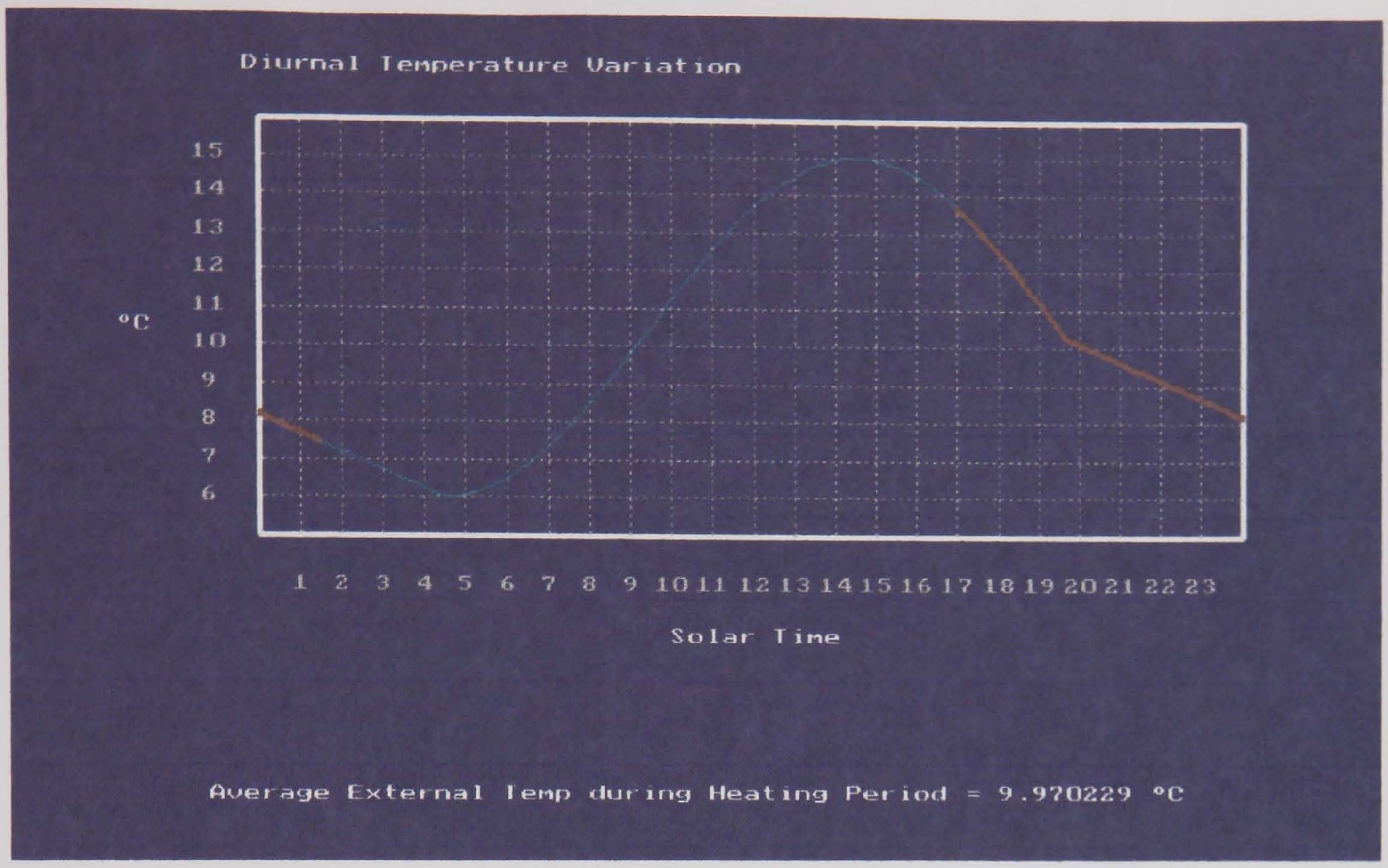
In real life buildings are not in a steady state, as even if the internal temperature is kept constant the external temperature will continuously vary. This is dealt with by assuming that short term fluctuations can be ignored and a representative value over a suitable time period used for the analysis, i.e. an average value.

The factor most commonly used to describe a building's thermal performance is the "U value" (in W/m^2 °C), which refers to the rate of heat flow through a unit area of the building envelope. This really only accounts for conductive losses, but is adequate for most purposes (and since the other major factor, infiltration, is difficult to evaluate, the U value tends to be all that's available).

A similarly useful, but rough, estimate of the driving force for heat loss is the "degree-day". This is an estimate of the amount of time that the external temperature is below a chosen "base temperature" (often taken as 15.5°). The base temperature is assumed to be such that no space heating is required as gains such as body heat, electrical equipment, etc., maintain the internal temperature. Degree days are based upon a sinusoidal daily temperature variation, which is a simplification, and they are based on average use of average buildings, i.e. they are wrong for nearly everyone, but not so wrong as to be totally useless. One shortcoming is shown by the following identical diurnal temperature curves, with the average air temperature being calculated for a typical day-shift and a typical night-shift.



Diurnal temperature curve chopped for Day shift



Diurnal temperature curve chopped for Night shift

Degree days would indicate the same heating load for both cases, but the actual average external air temperatures are around 13°C for the day-shift and 10°C for the night-shift.

In addition to these criticisms, the January 1997 issue of Energy in Industry and Buildings contained an article by Peter Harris, MD of Cheriton Technology Management criticising degree days. In correspondence with him he has identified the following errors which worry him and BRECSU:

- When the minimum temperature is further below the base temperature than the maximum temperature is above it, the degree day calculation produces an artificially high value. This usually gives too high a value in May, June, and October, and makes energy signature analysis inaccurate.
- He observes that diurnal temperature does not follow a sine wave, as has already been noted above.

- Degree days are calculated for too large an area, and are often based upon meteorological stations which are too far from the client site to be accurate representations of conditions on that site.

- Energy signature analysis assumes a straight line relationship between energy use and external temperatures. If degree days are used, the inaccuracies and breakpoints in the calculation of degree days cause the best fit to the data to be a curve, and not a straight line. This adds further elements of uncertainty to calculating the building's base temperature.

Degree day data is available from a number of sources including the Met Office, EEO, and BRE, or can be calculated based on local maximum and minimum temperatures at the site. Since the commercial supplier Vilnis Vesma is currently charging £140 per year for a met station's monthly degree days it makes sense to pay the Met Office £7 (only £3 for educational use) for an M data sheet and calculate your own degree days and working temperatures[1].

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[1] EEO recommended Best Practice for calculating degree days is the British Gas Method, this involves the use of a number of formulae for different relationships between maximum, minimum, and base temperatures.

When the external temperature is below the base temperature throughout the day

$$\text{Ddays} = \text{Tbase} - (\text{Tmax} - \text{Tmin}) / 2.$$

When the maximum external temperature is higher than the base temperature

$$\text{Ddays} = (\text{Tbase} - \text{Tmin}) / 2 - (\text{Tmax} - \text{Tbase}) / 4.$$

When the mean external temperature is greater than the base temperature

$$\text{Ddays} = (\text{Tbase} - \text{Tmin}) / 4.$$

These formulae have been derived empirically over a number of years and are accepted as the standard, though certain critics have suggested modifications.

This is the method used by the Eman package for calculating degree days, and gives similar degree day results for the RUTC site to those calculated by Ed Parry and his Energy Management team for the London Borough of Richmond upon Thames. Interestingly it doesn't necessarily give the same answers as

Using the U value and degree-days for a building an estimate can be made of the space heating energy required. This value can then be used in conjunction with energy bills and a site survey to see where savings are possible. No matter what information may be available on a building, a site survey should be carried out to gain an impression of the conditions and get the views of the people working there. Pure technical data may be misleading as it doesn't necessarily give the whole picture, e.g. the average internal temperature may be OK, but one area may be too hot and another too cold due to the effect of solar gains, drafts, or other factors. A building may seem to have a low energy consumption, but in fact be inadequately heated for comfort. What a manager writes down in a questionnaire is not necessarily what the workers on the shop floor think and they may know of potential savings to be made but their knowledge is often ignored by management.

3.2.2 The Conventional Method

The conventional method can be broadly summarised as follows:

1. Collect all the billing information and calculate the amount of energy used for space heating over the year.

2. Survey the site for possible losses and gains, and to gain first hand knowledge of conditions. Check out the lighting, water services, etc. Get dimensions, structural, plant information.

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a simpler method (based upon mean temperatures) which is frequently used. Leading supplier of degree day data Vilnis Vesma uses a system based upon the British Gas method. Vilnis Vesma charges £140 per year for an individual met station's monthly degree days, or £250 for monthly degree days for the 18 standard UK degree day regions. The Met Office charges £7 for 'M' data sheets containing one year's monthly maximum and minimum temperatures for a particular meteorological station.

3. Acquire the Degree-days for the year and apply any correction factors.

4. Calculate the building's U value.

5. Estimate ventilation losses based on required Air Changes per Hour.

6. Use the Degree-days, the U value, and other estimated losses, to find the theoretical heating energy required for the year. This is most unlikely to be the same as the real usage from the bills, but lets you know what kind of figure you are looking for.

7. Try and balance the theoretical against real consumption using the information from the site survey.

8. Rank the various losses and estimate possible savings and costs

9. Rank remedial measures by cost effectiveness

10. Present your report and collect your fee. (An alternate method is to undertake the energy management of a site for a percentage of savings achieved).

3.2.3 The Building Energy Signature Model

Over recent years the Department of Applied Energy at Cranfield Institute of Technology has been developing and refining Energy Management practices. These have been applied to a number of Energy Audits and development of the techniques has been the subject of previous Ph.D. theses.

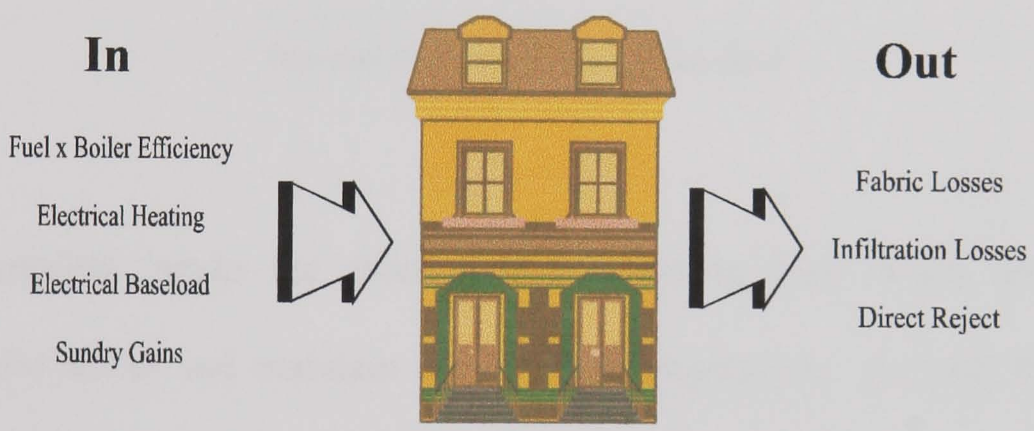
One aim of the energy management package was to integrate these techniques into a computerised energy management system.

3.2.3.1 The Energy Signature Model

The energy signature model as currently developed at Cranfield relates monthly energy inputs to degree-days over the course of a representative year for the site in question. (degree-days representing external air temperatures)

The model assumes fairly constant activity levels and thermal performance of the building and its services throughout the year. Major incidents such as a strike or changes to the structure, equipment, etc., during the period of interest would make the model suspect.

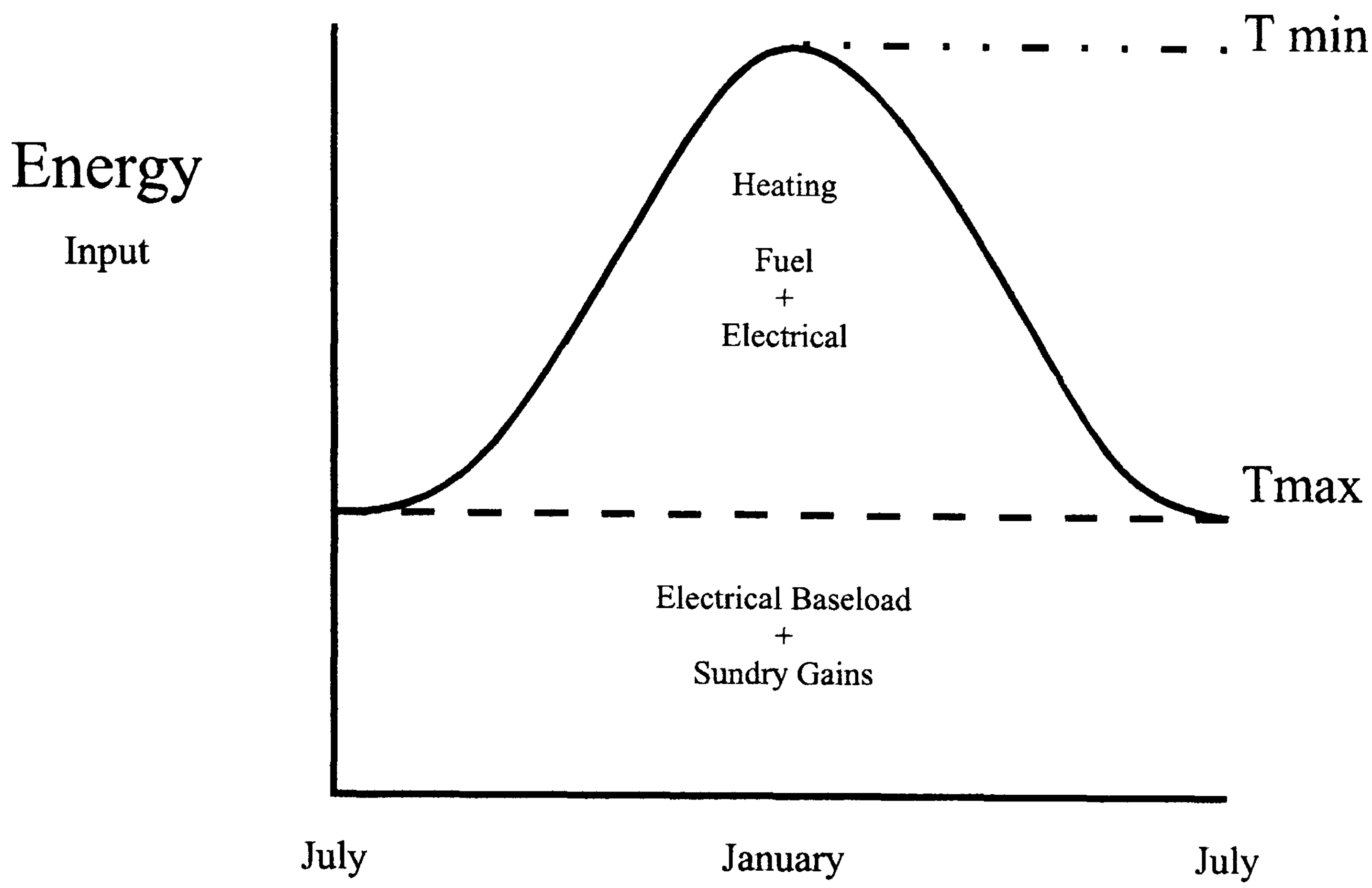
3.2.3.2 Building Energy Flux



Energy Flows through a building

To maintain thermal equilibrium, the flow of energy into a building must equal the losses from the building plus any change in stored energy within the building (due to heating of the thermal mass). To all intents and purposes the stored energy is a function of the difference between the internal and external temperatures.

Energy flows into the building are thus of two types, climate dependent which will vary seasonally, and climate independent.



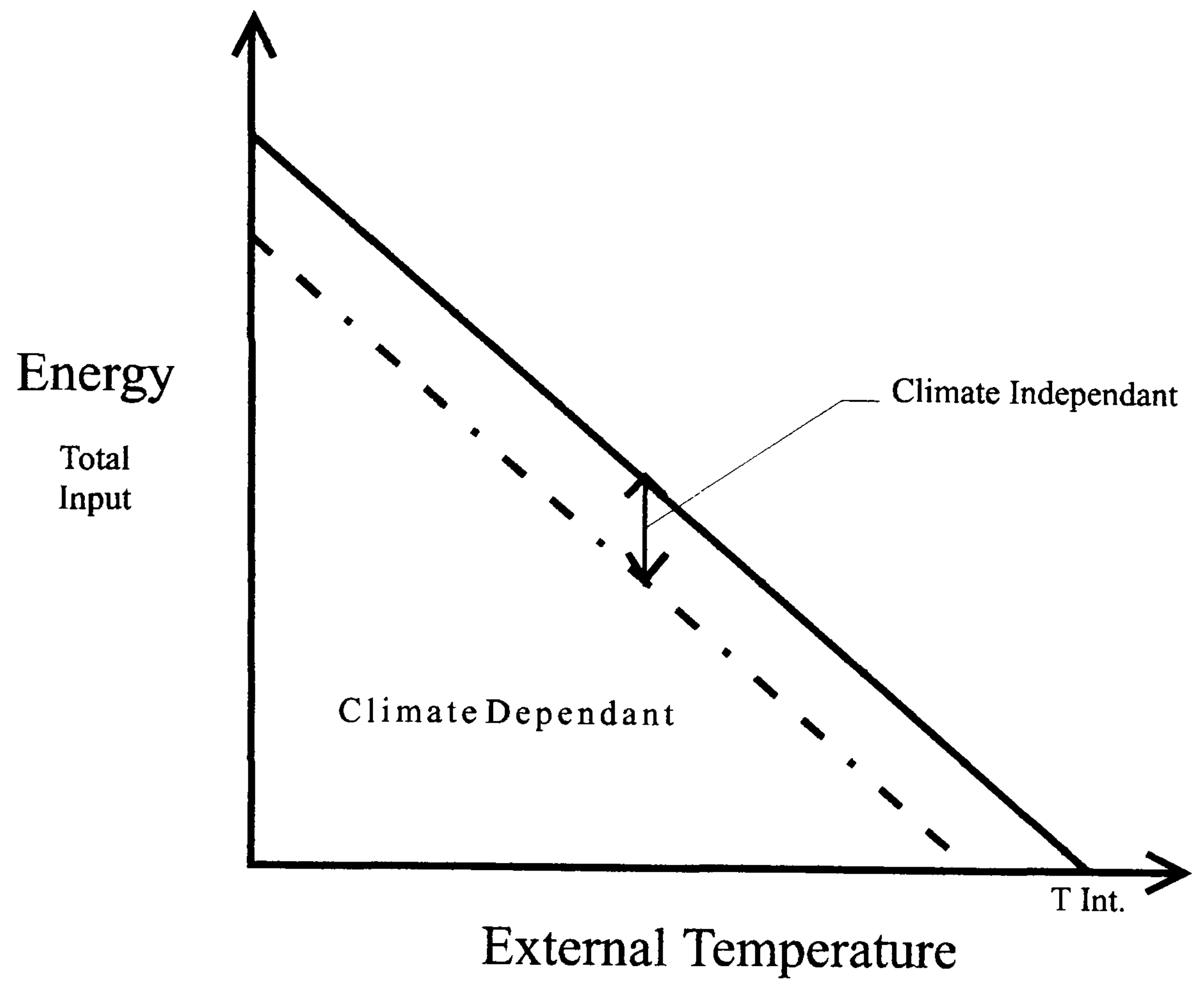
Seasonal demand and constant baseload

Climate dependent inputs are those such as heating fuel, which are needed to compensate for losses and maintain the internal temperature. As such they will vary through the year in response to the external conditions.

Climate independent inputs are those such as power for manufacturing processes, metabolic gains, etc., which should remain fairly constant through the year.[1]

[1] It was expected that lighting loads would be climate dependant, because in summer one would expect less need for electrical lighting. In practice this doesn't seem to be the case in most buildings, a) because people don't turn of unnecessary lighting and b) because many buildings are too deep for natural lighting to suffice.

3.2.3.3 The Energy Signature



Relationship of energy input to external temperature

Over the heating period, for a fixed internal temperature the total energy input is taken to be inversely proportional to the external temperature. This energy input has a variable heating component with a constant base-load and sundry gains component.

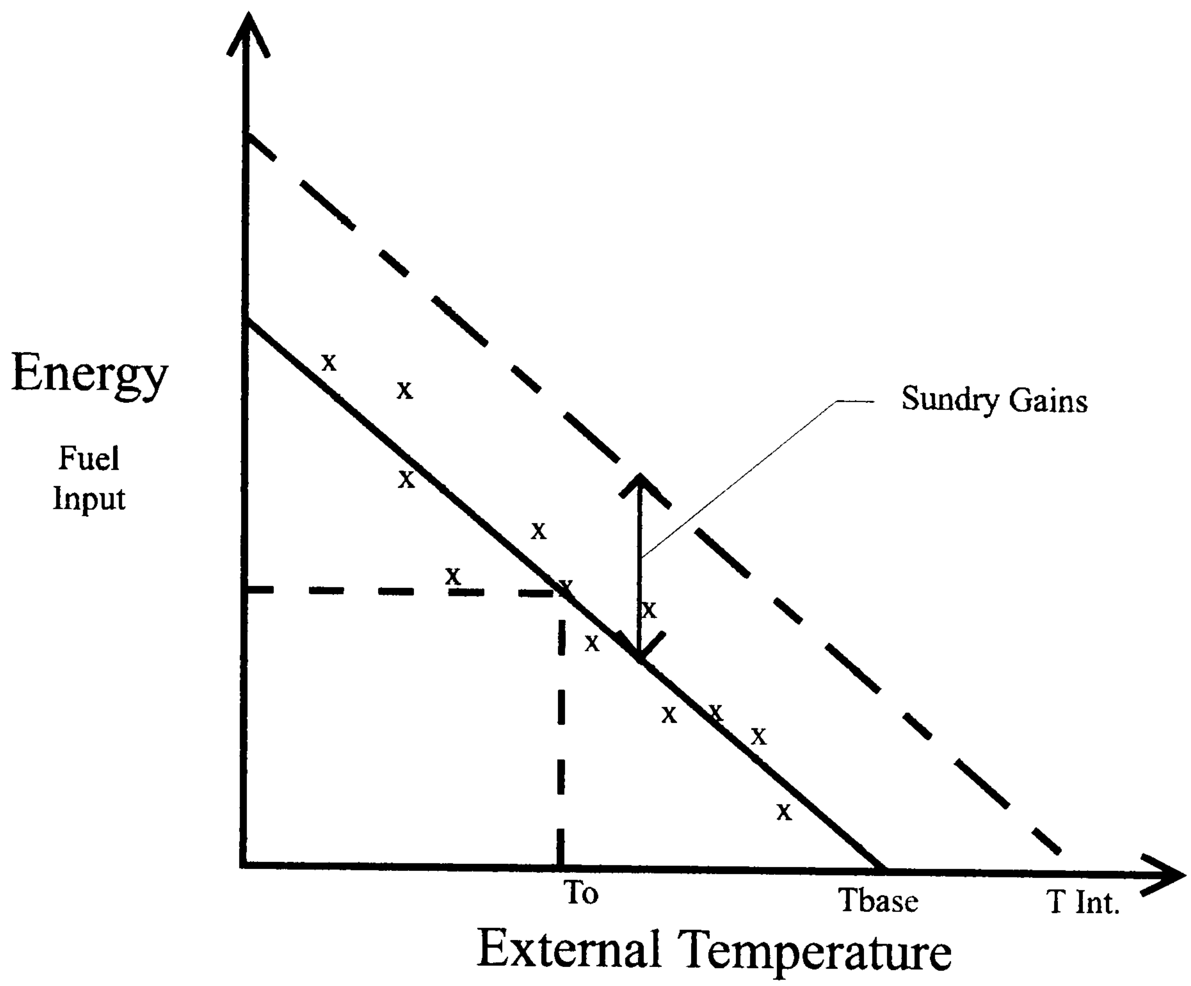
The electrical heating component (climate related and varying) and base-load (climate independent and constant) can be found by plotting monthly electrical consumption figures against external temperatures. The base-load can be assumed to be the minima (horizontal section in the absence of air conditioning, etc., in summer).

Similarly the total heating energy input can be correlated against external temperature, leaving just the Sundry Gains as an unknown. However, the sundry gains are effectively climate independent and can be taken to be constant.

A base temperature for the site can be derived from the graph of the input electrical and fuel energy versus external temperature. This is the external temperature at zero climate related input, i.e. where no direct heating is needed because the sundry gains are sufficient to maintain the desired internal temperature. Alternatively, it can be viewed as what the internal temperature of the building would be for the same heating input energy, but without any additional sundry gains.

Since the relationship between external temperature and energy input is linear, the ratio of sundry gains to heating energy over the year must be the same as the ratio of the temperature difference generated by the sundry gains to the temperature difference between the base temperature and the average external temperature.

$$\mathbf{SG / Heating = (T_{int} - T_{base}) / (T_{base} - T_{ave})}$$



Derivation of Sundry Gains

As a result, all of the significant energy inputs are known or can be derived from climatic data and energy bills for the site, but the breakdown of energy outputs is still unknown. However, to maintain the energy balance the total energy out must equal the total energy in.

Energy outputs from the building can be broken down to fabric losses, infiltration losses, and direct reject.

Direct reject is site specific but likely to be generally small compared to other losses. Where it is significant it is likely to be derivable from hot water flow rates, etc., i.e. it can be identified and evaluated.

Fabric losses can be found from a calculation of the building U value based upon plans or a site survey, and the difference between the average external and internal temperatures.

This leaves infiltration losses, which are difficult to directly quantify but can be derived since the total energy out and the other output components (fabric and direct reject) are known or are calculable.

Energy In = Energy Out

(In Steady State)

Fuel x Boiler Efficiency	*Fabric Losses*
+	+
Electrical	*Infiltration Losses*
+	+
Sundry Gains	*Direct Reject*

The Building Energy Balance

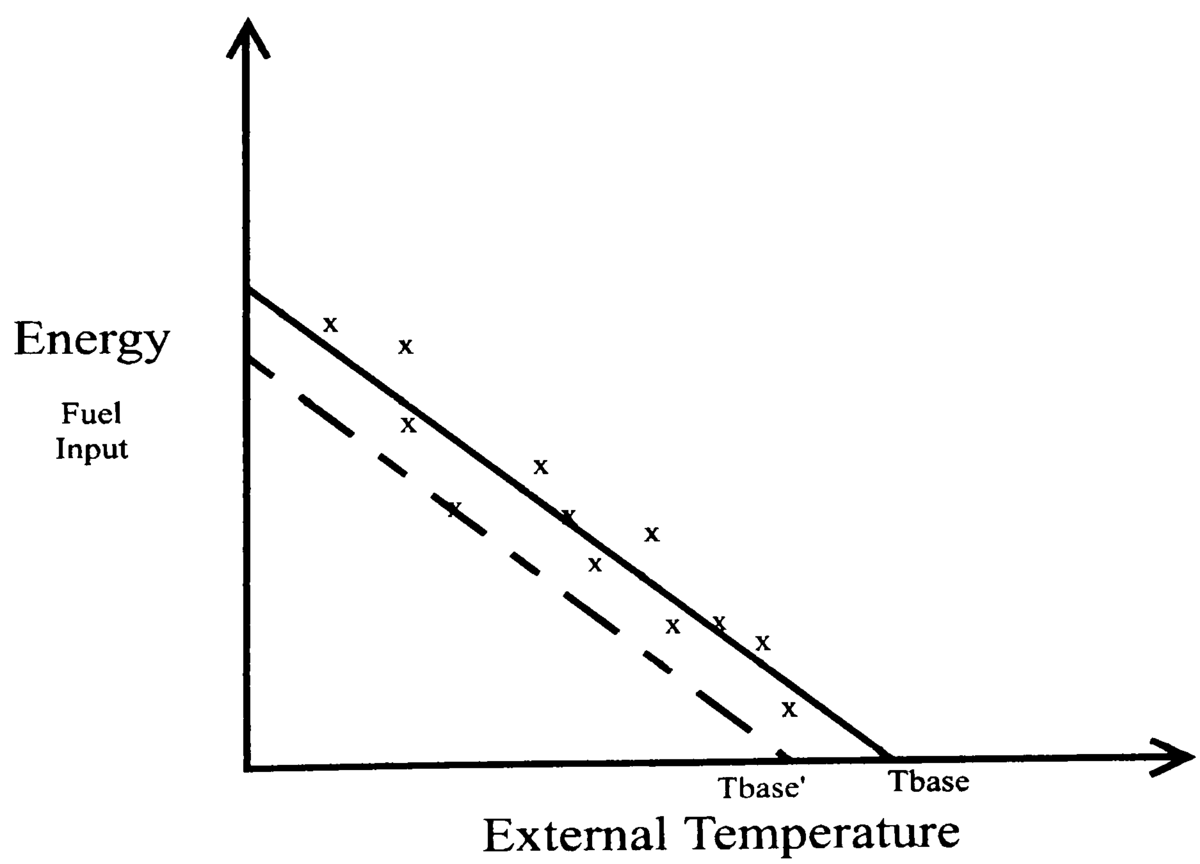
Component	**Quantifiable from;-**
Fuel Energy	Energy Bills
Boiler Efficiency	Site Survey
Electrical Heating and Base-load	Correlation of Electrical Bills against External Temperature
Sundry Gains	Correlation of Heating Energy against External Temperature
Fabric Losses	Site Survey and Plans
Direct Reject	Site Specific, may be identifiable from Energy Signature, Site Survey, CIBSE guides, etc.
Infiltration	Derived from the Energy Balance

The correlation of input energy against external temperature thus allows the construction the building energy balance, but other significant information may also be derived from the graph.

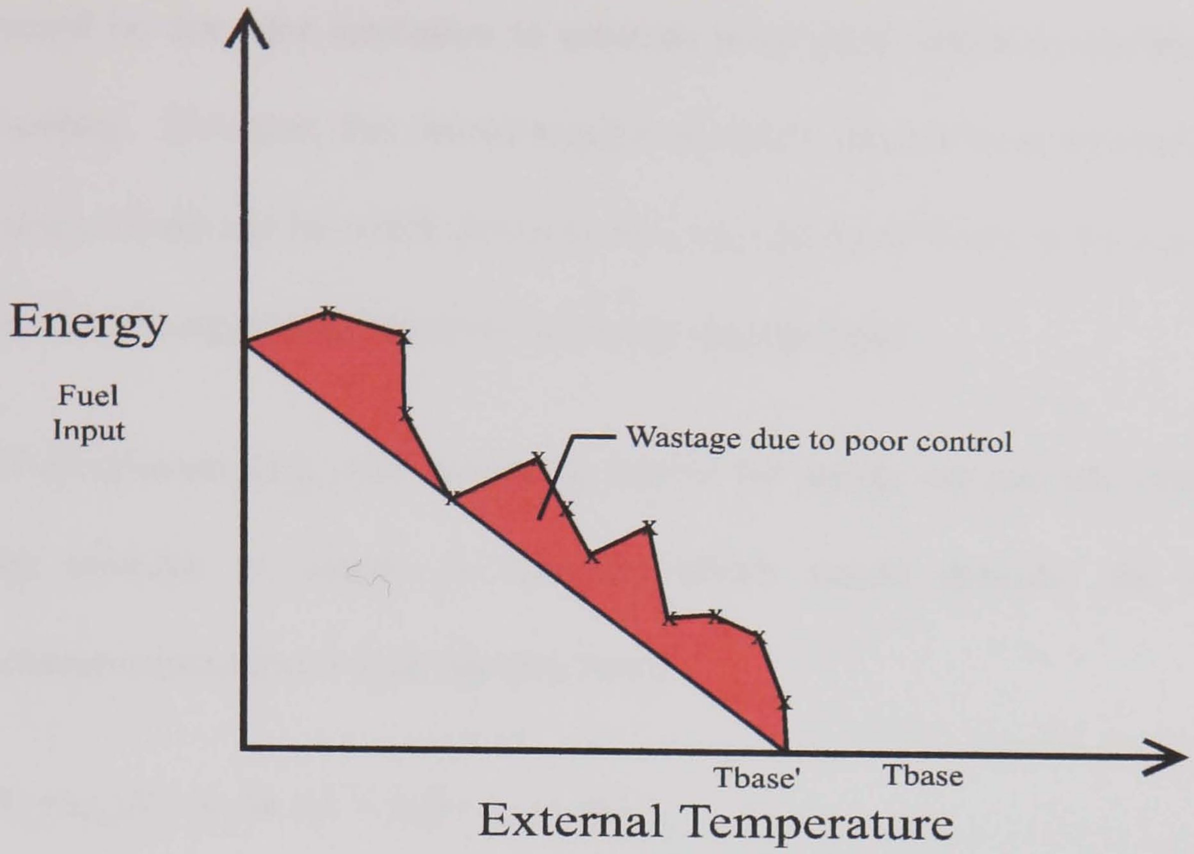
3.2.4 Possible refinements to the Energy Signature model

3.2.4.1 Control Accuracy And Lower Base Temperature

The straight line graph is the result of regression of a number of scattered points representing energy and temperature for particular months. If we accept that the building impedance, activity levels and so on are effectively constant, and that the correct comfort conditions were maintained throughout, then points falling above the regressed line represent wastage of fuel due to unnecessary heating. This unnecessary heating is due to inaccuracy of the control systems, so possible energy savings by improved controls can be quantified. Taking this logic a step further, points below the line should be providing the correct internal conditions for lower heating input, so it should be possible to work on a lower line for input energy vs. external temperature, with resulting lower base temperature for the site. This would imply a larger sundry gain component and lower heating requirement.



The true base temperature is likely to be below that given by the best straight line



Wastage due to poor control can be estimated from the graph

3.2.4.2 Normalisation

Energy inputs from bills should be normalised on a man-days worked per month basis to compensate for holidays, short working, etc.

3.2.4.3 Secondary Correlations

A criticism of the existing energy signature model is that infiltration losses are only found indirectly from the inequality of the energy inputs and outputs to the building. Correlation against meteorological data offers an alternative where wind speed data is available.

It should be possible to correlate wind speeds against energy consumption to get a forced infiltration factor for a building. This would entail extra costs, but it is an option where the simple energy signature model is in question. Wind speed data is available from the Met Office on a daily but not monthly averaged basis, so considerably more data sheets would have to be purchased to get accurate wind data for a site. The same could be done for insolation to estimate solar gains and also rainfall for evaporative cooling. However, this would require relatively expensive investigation, and for most cases would not be worth doing as any correlation is likely to be insignificant against the large inaccuracies inherent in energy management.

If all relevant data were accurately known for energy use and site conditions it should be possible to derive an equation which would describe the building energy characteristics and would take the form:

$$E = k_1 \Delta T + k_2 W \Delta T + k_3 S + \ldots + SG$$

Where the first element related to the external air temperature, the second to wind speed, the third to insolation, and so on.

Unfortunately, SG is unknown and, apart from energy consumption, all of the data is estimated. There may also be other unknown factors having a minor influence. In addition there will be an error associated with the energy control systems. As a result it is not possible to treat the data as a simultaneous equation to derive external air temperature dependency, etc., but they can be estimated by graphical correlations. In special cases this may be worthwhile, but in general the fabric and infiltration losses are the significant ones, so the extra cost of data gathering and processing is not usually justified[1].

[1] Note: Ralph Wilby et al at Glaxo Wellcome Operations tried to correlate sunshine hours, cloudiness, etc., against energy usage on their Temple Hill site, but could find no significant correlation despite accurate and frequent measurements taken on site. This suggests that, except in very rare cases where everything can be controlled, there is no point in attempting to do this.

3.2.4.4 Previous Work

There have been a number of relevant pieces of work in recent years, though none of them are directly related to this project since they all deal with the exhaustive analysis of a particular site and the aim of the energy management programme is to be widely applicable based upon a small amount of characteristic data without needing much site specific types of information.

Many of the reports are fairly similar to each other, and do not warrant detailed discussion here. It is necessary to identify those aspects of energy management which are generally applicable and do not require specialist knowledge of the company and it's business (i.e., procedures which are widely used and are not highly site specific). One outstanding common feature is that most sites could benefit from simple low-cost and even no-cost measures. Ignorance, misconceptions, and poor maintenance, resulting from a low importance for energy consciousness on the corporate level cause relatively large wastage, it is unlikely that any other resource apart from water is treated with such day to day indifference.

3.2.4.4.1 The management and implementation of Energy Thrift in Hospitals.

- EA Adderly PhD thesis.

Adderly uses the "energy signature" method of relating energy input to degree-days to estimate fabric and transmission losses from energy bill data and a simple building model.

He used common factors from a number of energy audits and the DHSS Encode system's programmes to create his own suite of Basic programmes as tools for modelling four hospital sites and generating an investment plan based upon a catalogue of energy thrift measures. Apart from being designed for hospitals, the programmes are quite site specific requiring detailed understanding of, and information on, processes on the site. They would be a useful tool for engineers running a well managed site with reasonably good energy management already in place. Rather than identifying major wastage in poorly run sites it would be useful for trying to identify cost effective improvements on a well managed and monitored site. For a generally applicable system calculating very precisely the savings possible by, for example, a marginal improvement in boiler efficiency, seems a bit pointless when it is likely to be insignificant compared to the effect of improved staff awareness and good housekeeping and the precision will probably be swamped by the inaccuracies in measurement and control. This is not to detract from the programme, which is very useful for it's target sites, but on a smaller, poorly managed, site the cost of acquiring and processing such data is likely to far out weigh the advantages. Adderly's set of programmes are well developed tools for fine tuning energy use on a particular type of site, i.e. a hospital, which already has a well developed energy management infrastructure, and the energy efficiency of which an earlier study showed to be dependant on only 28 variables (and a well defined set of 42 energy thrift procedures whose pay back periods were known). It is far removed from the sort of general purpose programme needed for the majority of sites visited during the development of the current project, where energy management is an unknown concept and viewed with suspicion. At a later date someone could develop a series of such specialised tools as bolt-on modules for the general purpose programme, with a separate one for each type of site (manufacturing, school, office, etc.), but each bolt on would be a major exercise in itself.

Following Adderly's method, a site survey would be carried out to determine rates of energy consumption, identify areas where significant savings could be made, identify thrift measures to effect those savings, and devise energy monitoring schemes.

Information from the site survey would then be processed using his "Thrift" suite of energy management tools;-

- "Create" contains an index of the hospitals and relevant data, it allows the creation of a "property" file of data for each hospital.
- "Data Set" inputs data from the site survey, derives the energy signature for the site , develops zonal models, and produces energy balances.
- "Measures" records consumption and costs which the energy manager or auditor has worked out (does not contain a set of generally applicable measures).
- "Model" models the interaction between the different energy thrift measures which have been proposed by the auditor, allowing the performance of various investments to be predicted over various project lives.

A report to a standard general format would then be manually prepared containing;-

- Summary
- Site description

- Energy audit
- Description of energy using systems, controls, condition of plant, recommendations, and costs.
- General conclusions
- Summary of recommendations ranked by SPBP
- Appendix of readings and example calculations

There is no real point in simply updating what Adderly has done because A) It's been done, B) Specialist knowledge and experience of Hospitals would be required, C) Adderly's specialised hospital oriented system is largely irrelevant to the types of site the general purpose energy management programme is aimed at.

3.2.4.4.2 A Study of Energy Use in a General Hospital
- K. Herriot M.Sc. 1987

Aims;

- To compare a chosen hospital to national standards.
- To assess effectiveness of energy management systems.
- To comment on the successes and failures of the energy conservation program.

North Middlesex Hospital was chosen for the study. This hospital consists of 530 beds in 36 blocks, but attention was focused upon the 1970's tower block, which was the main consumer. This block was under an energy management system based upon the DHSS "Encode" programme. Prior to 1985 energy conservation and monitoring had been by plotting monthly fuel consumption against degree days, with any deviations being investigated. Encode offers a methodology for surveying and auditing buildings and their energy requirements, and ranking possible cost reducing investments. It includes "Enbuild" and "Encomp" programmes to analyse the building energy usage and investment paybacks respectively. Enbuild was found to be very subjective and difficult to interpret. Encomp ranks projects based upon an idealised load estimated from past records. Encomps decisions are based upon lowest initial cost and shortest SPBP rather than energy savings.

The energy audit found that, despite A/C, windows were opened for ventilation in both summer and winter. there was also widespread use of artificial lighting in unoccupied, day lit rooms. Record keeping was poor. There was little useful energy consumption data on a building basis, only for the whole site, despite the energy management system.

Heating was by a steam system from a central boiler house. This system, along with the A/C cooling towers and chillers, was due for replacement, making the assessment of energy savings difficult. Little recent data was available for the performance of the obsolete boiler and heating system, the last daily log disc being 9 years out of date, the plant was generally dilapidated and poorly maintained. Based upon condensate returned, Herriot estimated steam consumption for the block accounted for 80% of the oil consumption for the site.

The air conditioning was very ineffective, with no heat exchange or mixing with incoming air. To quote,"... it appears to be a badly conceived design suffering from the deterioration caused by 15 years of wear, compounded by poor understanding by those responsible for maintenance, control, and alteration. If that alone is difficult to condone, it is made worse by the obsession to reduce energy bills to the point where not only do the systems fall short of requirements but they fail to achieve compliance with statutory instruments relating to ventilation of internal areas".

Electricity accounted for only 5% of the energy used, but 30-60% (summer-winter) of the cost for the site. While Oil cost 0.27 p/MJ, electricity cost 1.072-500p/MJ (depending on tariff, maximum demand charges, etc.).

There was a "Transmittron MP100" building energy management system, but this was simply used to monitor conditions. It had no control over plant, with energy management functions carried out by humans. The two largest consumers, the boiler house and chillers, were not linked to this monitoring system. The main savings due to the EMS were from timed zone control and duty cycling of fans. There was no optimum start and stop and levels were incorrectly set with plant consequently always either on or off. The EMS was not being correctly used and many of the functions were inactive.

Herriot proposed energy savings by;

- Replacement of existing lighting with more effective modern alternatives.
- Speed control of the pumps and fans. Halving the speed results in reduction to 1/8th of the power consumption. Typical price of the necessary static frequency converter is £100/motor_kw.
- Exhaust heat recovery

- Improved insulation. The walls and plant were OK but there was a flat roof of 3,700m² with a u-value of 1.79 W/m²K. Adding a 50mm layer of polyurethane foam at £19/m² would have a simple payback period of 17 years.

Herriot concluded that there were no realistic standards available for hospital buildings, and that the systems on site were misconceived and misused. He recommended;

- Overhead heater battery control valves
- Recommissioning of air conditioning controls
- Overhaul of the A/C plant to bring it into specification.
- Renovation of lighting and fitting of motion sensors
- Establishing fan control feasibility.
- Reviewing heat recovery feasibility.
- Proper use of the Building Energy Management System.
- Review of correct operation of sensors.
- Consideration of time switching.
- Consideration of cycling and speed control for pumps.
- Plant room heat recovery.
- Insulation of the roof while re-roofing.

3.2.4.4.3 Industrial Energy Analysis and Conservation

- J Dorling PhD thesis 1989

The project was a general analysis of energy used on a site of 270 acres, with 5 companies operating under one parent. The supply was common but accounting was separate for each company. There was an interruptible agreement for gas supply to the boiler house, a non interruptible for gas direct to separate buildings and an electricity supply. The boilers were dual fired gas/oil, switching to oil if the gas was interrupted.

Dorling found a good correlation between monthly energy consumption, production (taken as a measure of activity level), and degree days on site.

A tour of the site revealed compressed air leaks, draughts, unnecessary heating, unnecessary lighting, etc. Windows were open for ventilation in heated areas. High pressure hot water (180°C, 200 psi) boilers accounted for over half the energy demand, and their efficiency could be improved and optimised. There was no monitoring and poor instrumentation, a small investment in this area would give significant savings. Although one boiler would generate enough heat the flowthrough is insufficient for the demand of the plant, resulting in often running both boilers at 40% of their capacity. Westinghouse controllers on the boilers measured flow temperature, fuel and air consumption, pressures, flue gas temperatures, and flue gas oxygen concentration.

The boilers were then data-logged on a 15 minute basis, giving overall boiler house efficiency and levels of operation, allowing identification of specific areas of wastage and for performance trends to be analysed and fed back to improve control. Environmental data including solar irradiation, wind speed and direction, air temperature, and humidity, were also measured

The model for the site was a simple steady state one, using constant monthly temperatures and the assumption that all energy input is lost by fabric and ventilation losses. Solar and similar gains were ignored. The conclusions of Delorme (CIT 1980), that dynamic effects are not significant when dealing with long term predictions, were justification for the steady-state model.

Dorling then wrote simple routines in Basic to manipulate audit data and produce graphs, tables, etc., on which the audit report could be based. He discusses the possibility of a programme to input audit data, do routine work, compare to standards, etc., but didn't develop one because;

- He was not keen on software development.
- There was too much work involved in database creation.
- Data would be generalised and possibly not relevant to a specific case.
- There would be difficulty in producing a user-friendly format.

3.2.4.4.4 Abergele Hospital Energy Survey

- PS Woods, CIT 1988

Abergele Hospital had an annual energy bill of £148,000, which Woods estimated could be easily reduced to 103,850 for an SPBP on investments of 4.2 years.

Tariff analysis suggested savings from changing to a two part maximum demand tariff.

50% of the energy was used in space heating. To reduce this Woods recommended loft insulation, draught-stripping, and improvements to boiler house operation.

Loft insulation at £5/m² would have had an SPBP of 5.7 years, external wall insulation at £30/m² would have had an SPBP of 14 years. Draught-stripping would have had an SPBP of 2.5 years

Woods also suggested converting to a low temperature hot water system instead of steam heating, and considering installation of CHP.

Heavy fuel oil accounted for 92% of energy on site, and 72% of the cost. Boiler losses accounted for up to 6% of this, and 23% went in flue gas losses.

Blowdown losses accounted for 508,000 kg p.a. of steam, equivalent to 1097 GJ p.a. The blowdown autocontrol was unserviceable, and Dorling recommended installation of a boiler autosequencer. The feedwater hotwell was uninsulated.

Only 50% of the condensate was returned, resulting in a loss of 1409 GJ p.a. As well as increased heating of fresh water, this entailed increased blowdown and water treatment.

Poor lagging of steam and condensate lines resulted in a distribution loss of 3523 GJ p.a. There were live steam leaks. The insulation was of asbestos and difficult to access, making replacement disruptive and expensive.

Lighting accounted for 13.5% of the electricity used on site, this could have been reduced by 20% by replacing triphosphor tubes with slimlines and using sodium lamps for external lighting.

3.2.4.4.5 Energy Audit of the Seckloe Centre

- N Cliff et al, CIT, March 1992

The Seckloe centre was one of four buildings comprising the Sir Frank Markham Community School (1400 pupils) in Milton Keynes.

The Seckloe centre was 10 years old. It had its own gas fired boilers, one for hot water and two for heating. The boiler plant was well logged and had an average efficiency of 73%. There was optimiser control by an Ambiflex MF-1000, but there were insufficient thermostats around the building to make the best use of it.

The audit team produced graphs of kwH against month and external air temperature, maximum KVA against temperature, Gas consumption against month and external temperature, and gas against external temperature with savings due to a 1°C internal temperature reduction. Pie charts of energy use and cost by type were also prepared.

An Energy Balance was prepared and EEO NPI rating calculated. The team seem to have misunderstood the energy signature method, calculating sundry gains on the basis of estimated inputs due to occupants, lighting, etc., and then using this to estimate infiltration rates. This may also have been due to problems in calculating a reasonable base temperature from the limited data available to them.

Fairly standard recommendations were made;- turn off unnecessary radiators, fit TSRVs, draught-strip doors, service boilers, turn down thermostats 1°C, fit occupancy sensors to lighting. Apart from the TSRVs these measures give fairly short SPBPs, As stand alone measures the TSRVs pay-back period appears to be over 12 years, but they have bundled it in with an internal temperature reduction of 2°C and reduced infiltration rates giving savings for which the TSRVs alone can not be credited.

3.2.4.4.6 Energy Audit of the Headquarters of a Major Charity

- Raftery et al, CIT 1992.

The headquarters of Amnesty International comprised 2 buildings, 1920's factories converted to offices in 1980's. There were 300 staff and occupancy was from 9.30 a.m. to 6.30 p.m.

The two buildings had separate heating systems. Site 1 had four modern Regency gas boilers, with one old oil/gas boiler as backup. Site 2 had three open flue Hamworthy boilers. The piping was 1920's, with some corrosion and leaks. There was a standard radiator network with TSRVs fitted. The print room on site 2 had its own air handling unit, and there was air conditioning for the computer room in site 1. There were also ventilation fans in the canteen.

Electricity accounted for 37.5% of energy used, but 70.3% of the cost. Energy consumption was plotted against degree days. A correlation was found between external temperature and electricity consumption, indicating some electrical heating. This was found to be from electrical bar and fan heaters, if these were replaced by gas heating the costs would be reduced.

A large degree of scatter on the plot for site 1 indicated poor controls. This was also shown by windows left open in some areas while the heating was on.

Due to difficulty obtaining a suitable base temperature this group have also based sundry gains on estimated inputs from equipment, people, etc., and worked backwards. High infiltration losses were found, and explained by windows and the loading bays being left open.

Recommendations were;-

- To re-negotiate the electricity supply tariff.
- Institute energy conservation education.
- Isolate the old boiler from the H/W circuit (since it acts as a radiator when not in use)
- Stop supplementary electrical heating.
- Reset occupancy times on the controller.
- Reduce thermostat setting to 19°C
- Carry out more detailed economic and feasibility studies on infiltration losses, direct reject losses, Transmission losses, Conversion losses, lighting design, possibility of solar water preheating, possibility of replacing heating system.

3.2.4.4.7 GEC Hotpoint, Peterborough

C Beale etal, CIT 1992

This was a factory site manufacturing refrigerators and washing machines. There were 2000 staff working shifts, giving a 24h/day, 5½ day week. There was coal fired steam heating, with separate gas boilers for the social club and service workshops. The lighting was old and in poor condition.

The number and variation in buildings on site made it impossible to use the energy signature method effectively, but plotting electrical consumption against external temperature showed no seasonal variation, thus no supplementary electrical heating.

Energy against external temperature showed little scatter, indicating fairly good controls.

It was estimated that 30% of the energy consumption could have been saved by simple measures. The standard recommendations were made, but it was also suggested that the lighting system be replaced with Philips high frequency fluorescent luminaires. This investment would have made sense since the existing luminaires were in poor condition and due for replacement.

A water and waste audit was also carried out, with recommendations to;

- make maximum use of fixed fee borehole, rather than metered supply.
- re-circulate where possible.
- improve urinal controls.
- fit tap restrictors.

Although GEC Hotpoint complied with legislation there was no culture of energy/resource saving. The report recommended development of a rational environmentally conscious energy, water, and waste management programme with monitoring and targeting and workforce training.

3.2.4.4.8 The Energy Audit of a Tannery

S Grant, CIT MSc 1990.

Similar to previous audit reports in content. The site was Keunen Bros tannery at Irthlingborough. There was a coal fired boiler, providing steam heating. Weather data used was for Thurleigh, 12 miles distant.

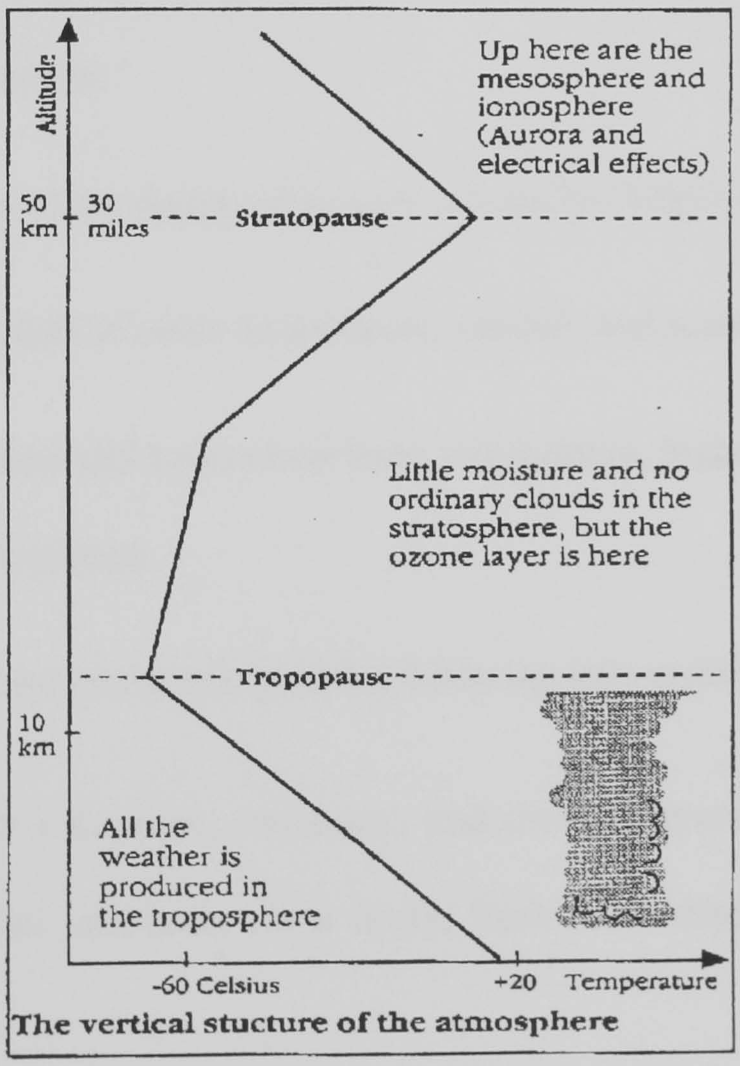
There was an interesting and useful background section on world energy reserves and usage, also tanning processes. This was a clear, interesting, and enjoyable report to read, but the site was very process specific and so the information was not immediately useful to the current project, It would possibly be worth re-examining it with a view to development and refinement of the package at some future date.

4. WEATHER BACKGROUND

The weather condition of primary interest for energy management is the external air temperature at the site in question.

The Meteorological Office have developed standard conditions for the measurement of Air Temperature. Measurement is by a mercury in glass dry bulb thermometer in white painted louvered Stevenson screen with bulb 1.25m above a short grass surface.

There is also an Altitude standard correction factor of 0.6°C per 100m to give sea level equivalent[1].



Variation of Air Temperature with Altitude

[1] (In fact Tmax correction 0.7c/100m, Tmin 0.5/100 because Tmax & Tmin are differently affected by altitude).

4.1 Sources of weather data

The air temperature, etc., at client sites is not likely to be measured directly, but inferred from published data for nearby meteorological stations.

4.1.1 The Met Office

The meteorological office publishes fairly complete data from about 140 sites around Britain for educational use. This information is available as "Monthly", "Daily", or "Hourly" data sheets for each station. These names are a little deceptive.

"M" data sheets give the following information;-

- Monthly averaged values of maximum, minimum, and mean temperature, rainfall and sunshine.
- Number of days in the month when various weather features occurred.
- Long term averages of mean temperature, rainfall, and sunshine.
- Highest maximum and lowest minimum temperature, highest rainfall, and dates on which they occurred.

"D" data sheets cover one month and give the following information;-

- Daily values of maximum, minimum, and mean temperatures over grass and concrete, rainfall, sunshine, snow depth, fresh snow depth, mean wind speed (not direction).
- Days on which various weather conditions occurred
- Monthly means and/or totals of the weather elements reported

- Extreme values of temperature, rainfall, and sunshine, and the days on which they occurred.

"H" data sheets give values for various data taken at 9 a.m. each day over a month, they contain the following information;-

- Dry and wet bulb temperature, dew point temperature
- Vapour pressure, humidity, mean sea level pressure
- Wind speed and direction
- Visibility, cloud cover, type of weather.

There are around 400 weather stations for which data can be requested, but many do not supply comprehensive data. For educational use only the price is £3 per data sheet, charges for commercial use are higher at £7. A limited number (4) of example sheets can be obtained free of charge.

4.1.1.1 Temperature measurement spacing

For accurate estimation of weather conditions at intermediate points weather stations must be close enough together that their measurements are broadly similar. This allows confident interpolation of conditions at points between them. The generally accepted correlation coefficient between weather conditions at two adjacent stations is 0.7. This figure is dependent on the most variable climate element measured, usually rainfall.

Yamamoto has shown a correlation coefficient of 0.85 is equivalent to a station separation of 100 km for mean daily temperatures[1].

The World Meteorological Organisation gives the following recommended spacings for sites measuring temperature;-

- Rural uniform terrain 160 km
- Urban terrain 2-3 km
- Coastal areas 15 km

Additionally, spacings can safely be 5 times as much parallel to a natural boundary, such as the coast, as perpendicular to it. In Britain the average meteorological station spacing is 20 km. Where clustering occurs it is in densely populated areas, i.e., where client sites are most likely to be located, or where local conditions vary so that more information is required to interpolate accurately.

4.1.2 The Press

Newspapers such as the Guardian publish daily weather conditions for a number of sites across Britain. This information is nominally free since it can be checked in the library, etc. It has a cost in terms of the effort of retrieving and processing the data, and the disadvantage of only giving a relatively small number of sites which are often close together.

[1] Variability of northern hemisphere mean surface-air temperature during the recent 200 years. Statistical Climatology. Elsevier 1980

Monthly degree day information for 17 regions of mainland Britain is published in the EEO's free journal Energy Management, it would be possible to approximate the site temperatures from this.

4.1.3 Client site measurements

As a last resort it would be possible to data log the client site to get accurate information, though the time and effort involved make that fairly impractical. Some clients may be able to supply weather data for their site.

Linacre gives a method to estimate mean site temperatures based on solar irradiance estimated from latitude. Unfortunately this doesn't allow for local wind effects, etc., and estimation errors build up at each stage so that the resultant inaccuracy is unacceptable for this project.

4.2 Diurnal Temperature Variation

The Meteorological Office and a number of other sources give similar descriptions of the diurnal temperature variation curve;-

The "Normal Variation" (defined for ideal standard conditions, a cloudless, windless day) follows a constant pattern. Ground temperature is at its minimum just after dawn. There follows an approximately sinusoidal temperature rise, reaching a maximum in the early afternoon (1300-1400 hrs). There is then a sinusoidal drop to sunset, and overnight a linear drop of around 1°c/hr. The maximum ground temperature can be 30°C more than air temperature, but ground minimum temperature is about the same as for air. There can be a rate of ground heating of 10°C per hour.

Air temperature follows a similar curve with a minimum at 30 minutes after dawn, and maximum between 1400-1500h. The minimum is due to a number of factors including cold air being drawn in by the upward convection of warm air further east while solar gains are still negligible. On charts the air temperature seems almost constant between dawn and the point of minimum temperature (T_{min}).

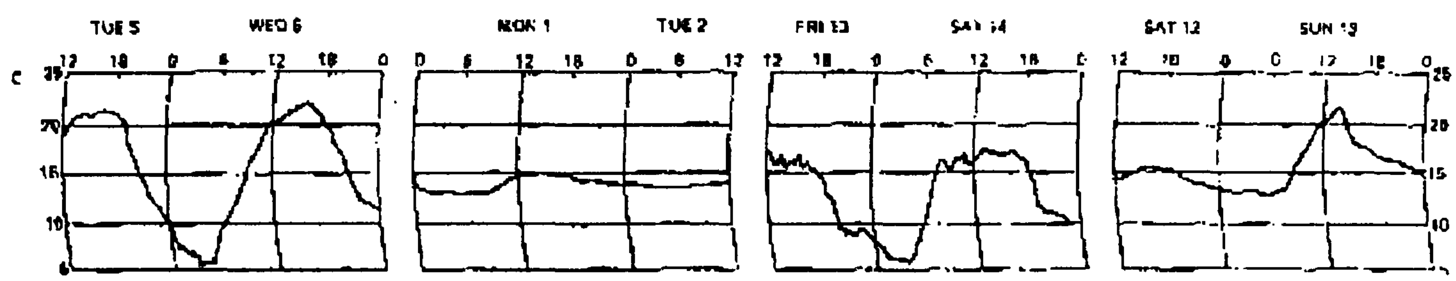
A slightly different curve for diurnal temperature variation is given by Chandler.

According to him minimum temperature occurs just before dawn. There is a sharp temperature drop just after sunset, then a gentle fall through the night. In winter the temperature is approximately constant for several hours before dawn.

The lowest temperatures are at dawn in February. Maximum temperature occurs around 2 p.m. from November to January, but is retarded to 4 p.m. by July.

Over a year the mean daily T_{max},T_{min}, T_{ave}, follow sinusoidal curves, as would be expected, with some scatter for daily values due to varying weather conditions.

4.2.1 Modifying Factors



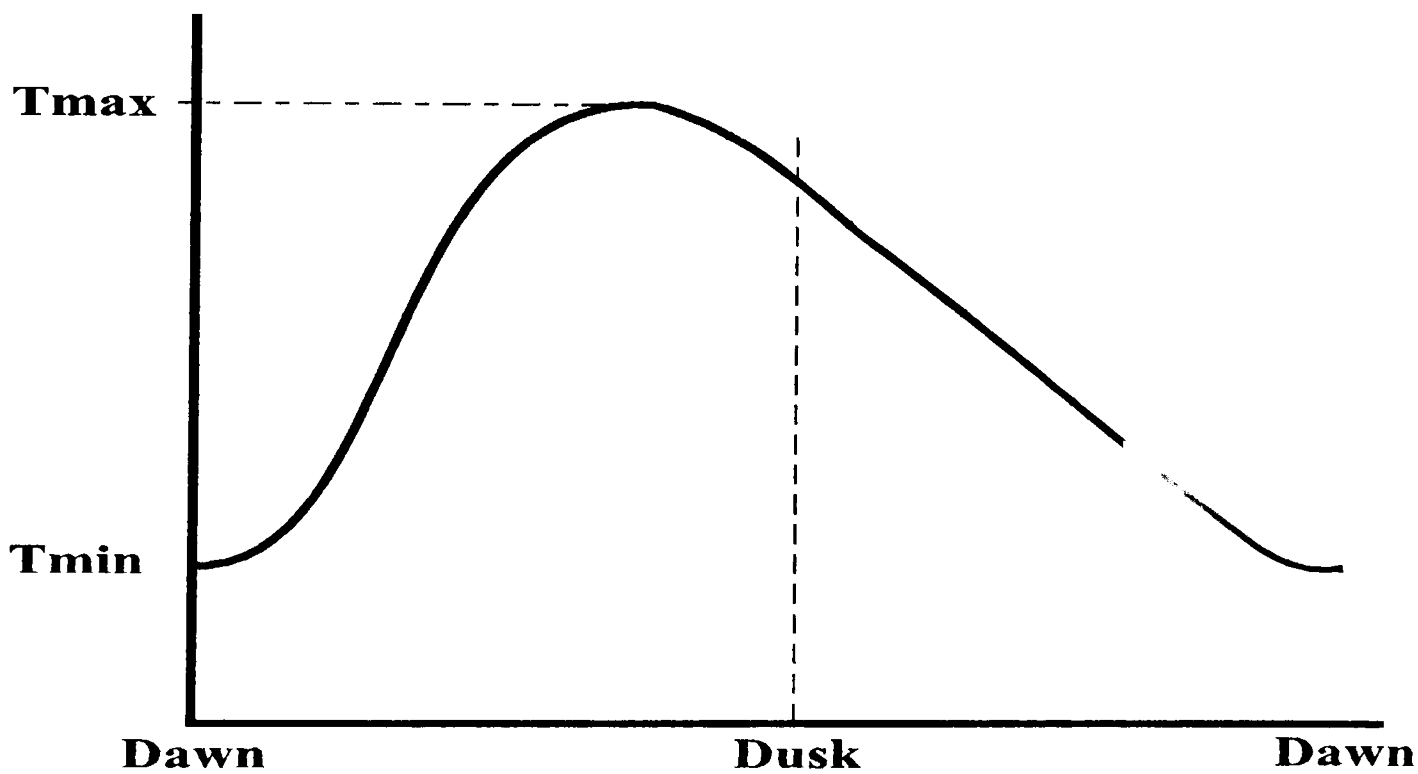
Clear Night and Day | Cloudy Night and Day | Clear Night, Cloudy Day | Cloudy Night, Clear Day

Various factors can alter the diurnal temperature variation from the normal variation.

Insolation, Water Vapour (greenhouse effect), Water (land warms and cools faster than water, dry soil faster than damp, etc.), Heating of air, winds, turbulence, etc. decrease the diurnal temperature range.

Cloudiness not only reduces the diurnal range but may blur the times of maximum and minimum temperature. For example, clouding over in the late morning will bring forward the time of T_{max}. Changing wind conditions can have a similar effect[1].

When averaged over a number of days the effect of such factors becomes smoothed over and the diurnal temperature curve will tend to follow the shape of the typical variation. In this way the average diurnal variation over a month will follow the typical variation curve, with maxima and minima averaged over the month.



Monthly Averaged Diurnal Temperature Curve

Although there is thus some disagreement between sources, it is likely that a curve following a sinusoidal shape from dawn to dusk and linear drop from dusk to dawn, with minima at dawn and maxima around 2.30 p.m., will approximate fairly closely to the actual diurnal temperature variation. Such an approximation will certainly allow better estimation of external air temperature over a period than is possible using degree days.

4.2.1.1 Local Effects

Local features can significantly influence temperature, often to a surprising degree. Variations of up to 3.3°C depending on exposure, position, etc., have been found between two thermometers 45m apart on the same site at Kew. Other influencing factors include height, distance from vegetation, wall mounted or free-standing thermometer.

4.2.1.1.1 Water

Much of Britain's climate is dependent on sea temperature. The sea affects the air temperature, which in turn affects winds from other regions, etc.

The sea has a large thermal capacitance and long reaction time, its diurnal temperature variation is very small, and its annual range is only from 10-16°C (off Cornwall). This thermal mass tends to promote persistence of weather conditions. The capacitive effect also gives a long response time to air temperature, reducing diurnal variation by up to 50% with respect to continental western Europe.

Another effect is the occurrence of on and off-shore winds due to the temperature difference between land and sea. This causes a diurnal wind speed variation up to 40 km inland from the coast. Further inland, diurnal wind speed variation is very small,

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[1] See Everyday Metrology, p55;- diagram 3.5.

with a maximum in the early afternoon and a minimum just before dawn. Diurnal wind speed variation is solar driven and hence greatest in summer. This should not be confused with overall wind energy, of which Britain receives most in winter[1].

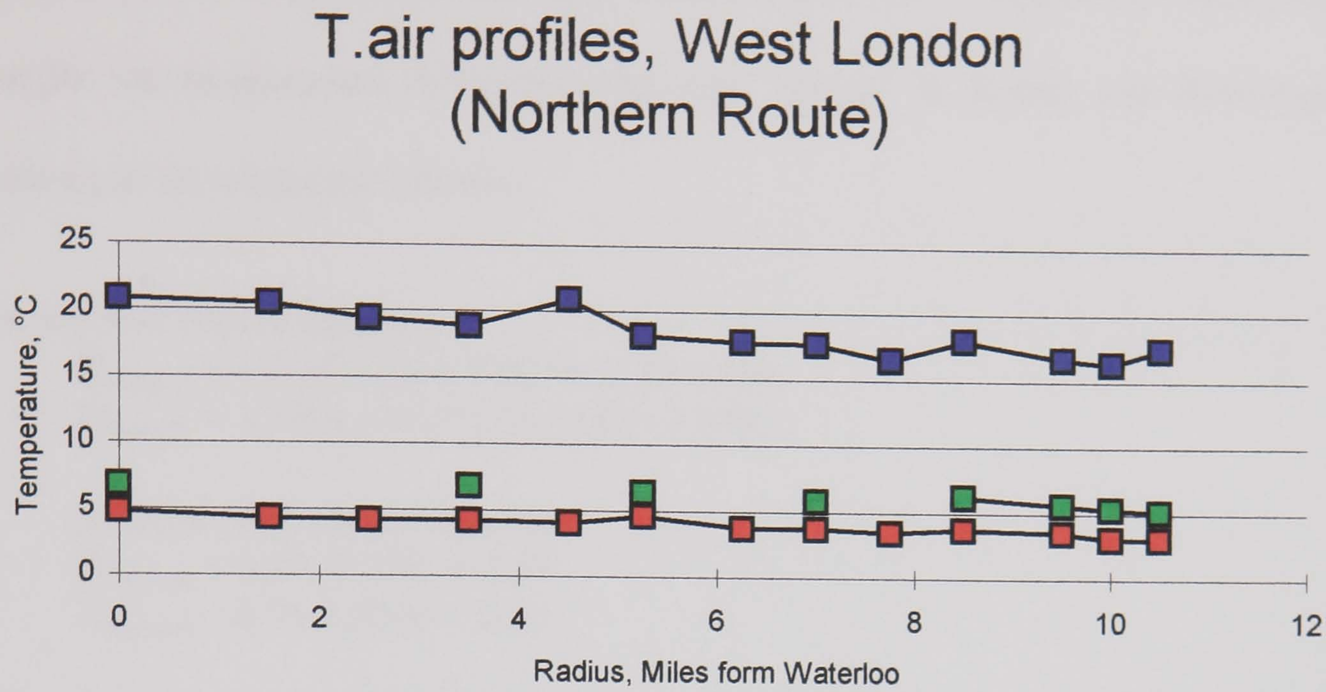
4.2.1.1.2 Heat Islands

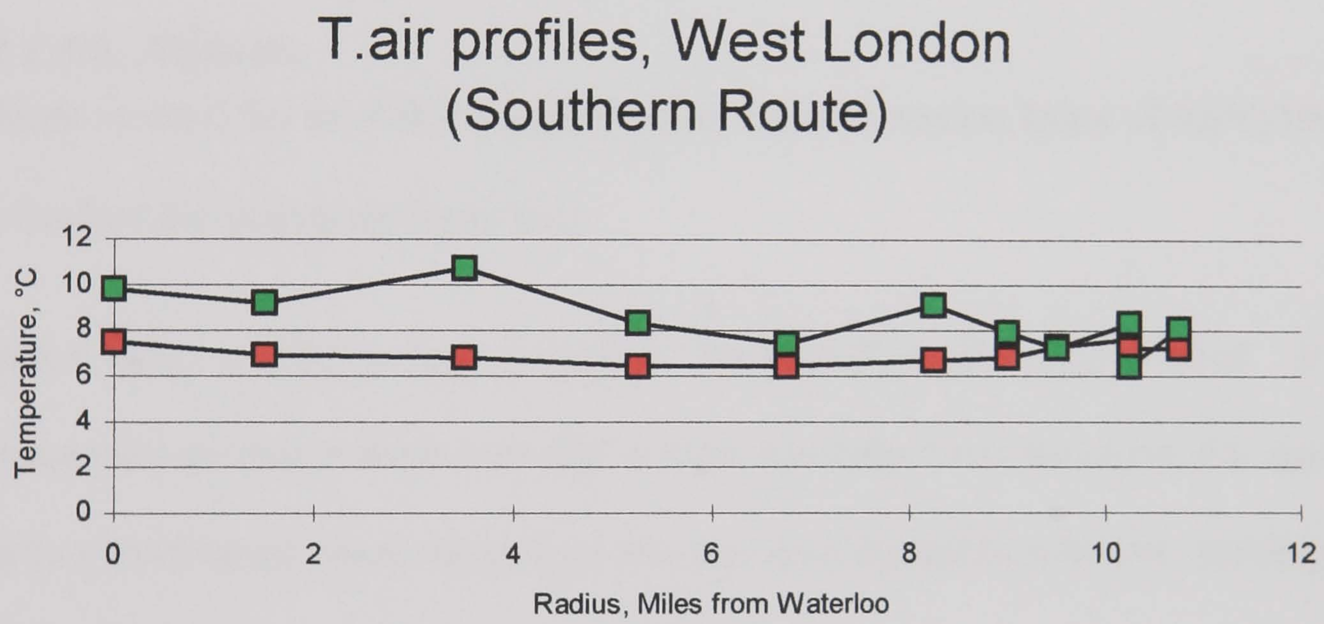
> *"But the Temperature of the city is not to be considered that of the climate: it partakes too much of an artificial warmth, induced by its structure, by a crowded population, and by the consumption of great quantities of fuel." - Luke Howard, 1820*

Various local features can have an effect on site temperature, urbanisation being one of the most significant. Over the period 1931-60 there was an average 1.7°C temperature difference between central London the and surrounding countryside.

As part of this project, temperature measurements were taken along two routes into London from the West, these showed approximately 2°C difference between central London and Twickenham.

[1] HC Hellard, met office.





London's Heat Island Effect

While differences in maximum temperature are small, the minimum temperature is elevated by the heat island effect of the city. Under some conditions the city temperature may rise at a slower rate than the surrounding countryside, causing fog, cloud, etc.

Researchers have quantified the heat island effect for a number of localities, for example the temperature differences between Wisley[1] in Surrey and Kensington in London can be related as follows;-

Summer and Winter Minima

D_{minsum} = 1.72-0.12N-0.17U+0.01T+0.15R

D_{minwin} = 1.69-0.13N-0.1U+0.04T+0.08R

Summer and Winter Maxima

D_{maxsum} = 0.83+0.03N+0.06T

D_{maxwin} = 0.75-0.03N+0.01U

Where D is the temperature difference, N is cloudiness (oktas), U wind speed (m/s), T temp(C), R temp range, all taken at Heathrow.
Unfortunately there is not yet a reliable correction factor for general use.

4.2.1.1.3 Altitude

Altitude in itself has an effect on temperature, and a correction factor of 0.6°C/100m is used to find the equivalent at sea level.

Another effect related to high ground is "katiabatic" or down-slope wind. In this phenomenon air near a slope is cooled at night and rolls down the slope, this can give very low local temps where the cold air movement is blocked by a hollow, building, etc. (frost hollows).

4.2.1.1.4 Persistence and Singularities

AH Perry of University College Swansea has been working in the area of synoptic climatology. He describes Singularities, a tendency for recurrence of some weather characteristic about a specified date in the year. If a spell of particular weather is firmly

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[1] Note: although Wisley is in the green belt, it is adjacent to two major roads, the A3 and M25, so it may be warmer than other areas the same distance outside of London.

enough established to pass through these critical dates that weather type tends to continue for some time longer.

Persistence is the tendency for a weather condition to carry over from day to day. Some large scale circulation patterns have a built in tendency to persist, or to evolve in one way in preference to another at certain times of the year.

"The Climate of the British Isles" gives the following examples;-

- SE England summer dry days tend to persist for periods of 8-10 days (Lawrence 1957).
- In winter the probability of a cold spell continuing for another day is 0.77 after 4 days, 0.83 after 6 days (Lowndes 1963).

This kind of phenomenon could be useful in inference of conditions from sparse data if Met Office information was not available. It could also help in determining sampling frequency.

5. INFORMATION TECHNOLOGY BACKGROUND[1]

5.1 Algorithms & Heuristics

Artificial intelligence (AI) is a concept which is endlessly argued over, because intelligence is hard to define in a way that is acceptable to all schools. To some people AI covers virtually all control systems, to others it is only applicable to the emulation of human thought processes, machines that think and learn (another philosophical minefield). In between there are various microprocessor based applications, from spell checkers to cruise missiles and beyond, which exhibit some level of "intelligence".

There are thus two approaches to computer programming depending upon whether the primary objective is for the computer to carry out a task by following instructions, an algorithm, or to learn for itself by trial and error, heuristically. Human beings learn primarily by trial and error.

Fundamental differences in structure and operation between the human brain and the PC make true artificial intelligence on a PC highly improbable. The programme is not intended to create true artificial intelligence, just a user friendly programme which can carry out the routine tasks of energy management, and which through pre-programmed rules would maximise the useful inferences and recommendations from a minimum amount of user input data. As such it constitutes an expert system designed to aid the human energy manager by identifying areas of possible savings. The human energy manager can then review the suggestions made and conduct further assessment.

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[1] The pace of change in electronic media calls for constant review of this aspect of the work. Things which were undeniably true a year ago are undeniably false now, options which didn't exist or were prohibitively expensive have become commonplace, and what is written today will have been outstripped by unforeseeable developments by the time that it is read.

The core energy management tasks are straightforward data processing, and best dealt with by an algorithmic programme. As expert system programming software becomes more sophisticated it would be possible to add an interpretative aspect to the energy management package, but at this stage the costs outweigh the benefits.

5.2 Interfacing With The User And Other Applications

Software functionality is dependent on a number of factors and preferences which are independent of the technical tasks which it performs. This section outlines the context within which the software design was undertaken.

From the programming viewpoint the simplest user interface is to have keyboard input and text output to screen or printer. This is adequate but not user-friendly, it doesn't appear inviting to the inexperienced operator. Adding graphics greatly improves the man-machine interface, particular for output where a graph for a process is much easier for the user to interpret than a table of values. A graphical user interface also makes it easier to input data and navigate around the package because each screen that is presented can give visual clues for recognition, function, and its relationship to the rest of the programme. The use of Icons reduces the chance of errors being introduced via the keyboard, operation is easier because there is less freedom offered to the user.

Interfacing the package with other programs increases its versatility and can be achieved by keeping relevant data in files which are accessible by a number of different applications. It is quite simple to store the data as text or binary files, but it would be better to use some standard database or spreadsheet file format which could incorporate additional information such as formatting and data linkages. It is possible to store data in Borland Paradox database table format, and access it from applications written in Borland C++, or some other programming language, or via products such as "Paradox Engine" which Borland sells for database development.

Another element of simplifying integration is the development of the programme as a Microsoft Windows based application, which (in theory) should result in a large degree of compatibility and shared functions with other Windows based applications. An added advantage of this approach is that Windows has become the standard interface and many people are therefore familiar with the operating environment.

5.3 Operating Systems and Environments

Operating systems are programmes which orchestrate information transfer within the computer hardware, control disc drives, input/output, etc. They provide "primitives", efficient sub routines which application programmes use to drive the computer hardware. The ones most users will be familiar with are the Disc Operating System for IBM compatible PCs in its PC-DOS, MS DOS, and DR DOS variations, and more recently Microsoft's Windows 3.x and Windows 95. Some other operating systems are Unix, Linux, OS/2, System 7, and Windows NT.

5.4 Choice of Computer & Operating System

The widespread use of IBM compatible PCs and Windows make them the obvious choices to maximise the range and extent of applicability of the software package.

5.5 Languages & Software

There are hundreds of programming languages and software packages available, each of which offers advantages and disadvantages compared to the others. The languages reviewed in the course of this work were limited to those which seemed most potentially useful for this kind of development. These languages tend to fall into families exhibiting similar features, either because they had been developed from the same original programming language, or because they had been developed for a particular type of application.

Basic and Visual Basic

Basic and early versions of VisualBasic were found to be clumsy to use, and they were known to have portability problems.

C and C++

Although very powerful, these are user-unfriendly and really intended for professional programmers.

Clipper and Appware

Clipper is based in DOS, and has a very specialised niche. For the present purposes it was felt that it offered few advantages over C, and that it would be overtaken by the newer visual development languages for Windows programming.

Pascal

Pascal was developed to teach structured programming and gained a foothold in personal and business use. It does not offer the power of C, nor the simplicity of Basic, and is not in itself suitable for the development of complicated programmes.

ADA

ADA is a structured programming language derived from Pascal and used extensively in military and nuclear power applications. A version of it generally available for use on the PC could not be found.

Prolog

Prolog is an Artificial Intelligence programming language developed at the University of Aix-Marseille as a replacement for LISP, it is good for particular AI applications but less versatile than C. Rather than the conventional range of functions and statements, Prolog is based around "Clause functions", which compare lists of objects, relationships, attributes, etc., to give rule based answers to questions. Limited mathematical and arithmetic functions are included.

Crystal

Crystal is an Expert System shell which allows easy construction of expert systems. The programme produces a Q & A type expert system, which searches through a tree of objects comparing their attributes to those stated by the user. As such it was not considered appropriate for the present task.

Mapbase

This is a "Spreadsheet on a map". It links with Dbase, etc. to give a geographical information system linking data to site location. Whereas Mapbase is a nice way of graphically presenting information it does not provide the range of functionality required for the present task.

Delphi

Delphi (released Summer 1995) is Borland's object oriented programming environment, code named VBK during development - Visual Basic Killer. Delphi takes Pascal out of the classroom and makes it a powerful programming language for professional use. It is effectively a Visual Pascal, but with greater power and versatility than contemporary versions of Visual Basic, and includes more pre-packaged application development tools than VB. Delphi applications are about one tenth the size and seventeen times as fast as Visual Basic applications according to independent evaluations.

Delphi also integrates well with standard database table file formats (those that comply with Microsoft's Open Data Base Connectivity specification) via the Borland Database Engine, and can be used for client-server applications employing Structured Query Language. This language is ideal for development of the applications such as that envisaged for this project, and so was the language chosen for final development.

6. ENERGY MANAGEMENT SYSTEM DEVELOPMENT

The energy management system was developed in three stages[1]:

1. Research of the available background information from published literature and real sites, and investigation of applicable information technology.

2. Development of a generally applicable paper-based system.

3. Design and development of a computer based system derived from the paper-based system.

6.1 Sites Used For Energy Management System Development

Aspects of the energy management system were developed in response to observations regarding energy management on a number of sites, as detailed below. Data from the sites was used for developing and testing modules of the computerised system such as the U value, energy signature regression, external air temperature, and NPI subprograms.

In two cases the sites concerned cannot be named because of a confidentiality agreement.

6.1.1 Richmond Environmental Information Centre

The Richmond Environmental Information Centre was a council owned office and meeting space which was sublet to local environmental organisations for nominal fees plus a service charge. It was largely the initiative of the Richmond and Twickenham Friends of the Earth, whose members originally managed it and continued to play an influential role. The original Centre in Red Lion House, Richmond[2], was surveyed because of concern over the service charges[3] expressed by Sheila Cleary who was Centre Manager, and because of an interest in making the building more energy efficient on the part of Terry Mills, chairman of the management committee.

The REIC occupied the ground floor of a council owned 4/5 story concrete and brick office building which is sublet to a number of tenants. There was a large open plan meeting and office area, with a library, four separate offices, a workshop and darkroom, computer room, kitchen, toilets, and conference room/centre managers office as separate rooms opening from it. The main entrance was through a double door via a single glazed lobby, there is a rear door onto a yard. The doors had originally been draught stripped but this was worn away leaving obvious gaps, some of the old metal framed windows were no longer tight fitting when closed, about 45% of the wall area was glazing..

On a November day with external air temperature of 15°C the room temperature varied between 23 and 27°C, despite the fact that all of the windows and doors were wide open and 4[4] of the 20 radiators were turned off. Those radiators which were in use were turned down to a surface temperature of 38 to 42 °C. The librarian said "It's always

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[1] In fact elements of the computer programme were developed while learning about computer programming and the available technology.

[2]The Centre has since relocated to Heath Road Twickenham

[3] The occupants only received a bill for the service charge and had no idea how much gas or electricity they were being charged for. Although they had a system of budgeting for energy costs they were not separately metered and simply paid for heating based upon the landlords estimate. Flat rate service charges can impede energy efficiency, they create an inequitable relationship between supplier and user where less conscientious tenants have no incentive to conserve, because it makes no direct difference to their costs, and less conscientious proprietors have no incentive because they can simply pass the costs on to their tenants.

[4] These were smaller office radiators under windows behind desks, where users felt cold due to the proximity of the window.

cosy in here, the first thing I do when I come in is take my shoes off because the carpet's lovely and warm". Temperatures in the library and adjacent toilets reached 30°C at floor level, and it turned out that the library was directly above the (uninsulated) boiler room[1]. Although most radiators were turned off at the radiator valves, hot water still circulated through un-lagged and exposed two inch diameter steel pipe work, which at 60 to 70°C surface temperature acted as a heater in it's own right (about 100W per metre of pipe). On looking at the building from the outside one could see that all of the occupied offices had their windows open, suggesting that the whole building was over-heated, not just the ground floor. Despite this some rooms apparently got cold because there were two portable gas heaters on site, though they were not in use.

The lighting was mainly 38mm Fluorescent strips[2], with a few 40 W GLS bulbs for general lighting and desk lamps. The lobby was fitted with a number of 40W GLS bulbs, of which only one worked when tested. The fluorescent lighting in the reception area was out of service. The conference room had previously been the display area for a small marketing company. It was painted and carpeted in dark colours and lit by four 100 W GLS spot lamps recessed into the ceiling, the effect was less useful than having a couple of 60 W pendants. The fluorescents were generally old and only replaced on failure. A number of lighting circuits (toilets, reception) were out of service due to "problems with the electricity supply", this caused a particular problem for users of the

[1] The boiler room temperature was about 32°C. The sides of the boiler room hot water tank were insulated, but the top was bare metal at about 80°C.

[2] Though the landlord had fitted slimlines in the boiler room.

disabled toilets. Only one of the four 5' fluorescents in the kitchen was in working order.

The gas boilers were on a 7 day timer, but seemed to be running continuously to heat offices in use at night. There was no zoning, so the whole building was heated even if only one floor (or even one office) was occupied[1]. If there were thermostats none of the occupants were aware of them and they could not be found.

There were three computers, which were generally left off because most volunteers had no need, or didn't know how, to use them. There were also two photocopiers which were turned off when not in use.

It was recommended that no investment be made in draught-proofing, etc., because the problem was overheating and lack of control. It was suggested that the REIC get together with other occupants to press the landlord to reduce temperature and improve boiler control, if possible to zone the building. It was recommended that the GLS and strip lighting be fitted with energy efficient equivalents, and that the conference room be re-painted and fitted with new luminaires.

While discussing energy efficiency in the REIC it was suggested that approaches be made to various manufacturers for free loan of their products in return for showcasing them. For example, different energy efficient lamps with information plates on the walls, double and triple glazed window panels, domestic appliances, etc.

[1] E.g. the REIC has evening meetings which may run to 10 p.m. or later, but has no control of the heating system.

Although it was not possible to make any changes to the building itself, REIC started to make progress on showcasing energy efficient appliances, but the council decided to reallocate the space to the company running the local parking wardens instead. For a short period the REIC was homeless, but was then relocated to another site in Twickenham. The energy efficient product showcase idea was shelved.

6.1.2 A South Coast Bus Garage And Offices

The client occupied 500m² of offices in an Admin block, two bus garages of 9,000 m² each (one of which is to be converted into light engineering units and sub-let), and 400 m² of workshops. The two garages were separated by some offices and washrooms

Energy costs were £39,237 for gas and £26,666 for electricity. The bills were unavailable because the project was only to advise on technical/structural improvements, another consultant was managing their billing and tariff analysis.

The Admin block was circa 1950, board walls with about 50% single glazing, roof wooden board with copper cladding and no insulation. There was no draught-proofing and large gaps were visible around the doors. The main entrance had a draught lobby which was too shallow, making it awkward to close one set of doors before opening the other, as a result the inner doors were left blocked open.

The building was generally too hot. Two room thermostats were fitted, but only one in the 1st floor NW corner appeared to be working. This was set at 22°C, probably to compensate for the failure of the other thermostat so that some areas would not be too cold. Minimum temperature in the building was measured as 19°C in the reception area adjoining the main entrance, the external air temperature was 1°C.

Lighting was a mixture of GLS and 38 mm Fluorescent strips. Light fittings were dirty, and some of the luminaires were poorly designed. Lighting was left on when not needed, e.g. in the canteen which is both well day-lit and unoccupied for most of the time.

The Workshops were in a concrete vaulted building, rather like an old aircraft hanger. The building was about 8 to 10 metres high to allow double-decker bus access, though this was no longer necessary for most of the building. The roof was fibre-board lined, but with no other insulation, large single glazed skylights ran along the length of the building. There were a number of extractor fans in the roof with no flaps to close them when not in use, so hot air was continuously lost. Some of the extractors had been removed leaving open holes. Walls were about 70% steel framed single glazing which was so dirty as to be opaque. There were wooden doors along one end of the building to allow access for double decker buses, these were uninsulated and had no brush-strip or other draught proofing despite a 25 mm gap under them. There were 150 mm diameter holes in the doors for hoses to be attached to bus exhaust pipes and passed out of the building (to prevent CO build up) but these were no longer needed. There were double doors into the stores which were supposed to be opened for deliveries, but in practice they were generally left open. There were also double doors into the paint shop, which were left open because of the paint fumes. There was a draught curtain between the inspection pits and the machine shop, but this was prevented from falling shut by stacked oil drums.

General lighting was by 300 W GLS lamps at roof level, task lighting was a mixture of GLS and fluorescent strip. Fittings were old and dirty, and often inappropriately placed, e.g. above high shelving.

Heating was by a steam system via old overhead fan coil units, the steam lines were uninsulated. The condensate tank and lines in the boiler room were insulated with asbestos, the presence of which was being addressed by a contractor.

Control was poor, with no zoning. Temperatures around the building varied from 16° to 26°C. Staff complained that the concrete floor could be freezing even with the FCUs running, and that it was possible to be working in very cold conditions in the lee of machinery or vehicles.

Compressed air systems ran 16 hours a day. There were numerous obvious leaks, and the pressure relief valve could be heard operating semi-continuously.

Garage 1 was vaulted concrete, uninsulated. The walls were about 50% single glazing, there were large extractors in the end walls. General lighting was by sodium lamps, sensor controlled in 4 zones. Fluorescent lighting was present in the inspection pits and office. The (often unoccupied) offices and washrooms were continuously heated by a gas fired radiator system, with a calorifier for hot water.

Garage 2 was steel framed with a corrugated aluminium roof. About 20% of the roof comprised dirty fibreglass skylights. The walls were about 30% single glazing, the rest being brickwork or uninsulated aluminium cladding. General lighting was by an array of fluorescents suspended about 2m above the height of the buses. Lighting in the inspection pits was provided by fluorescents and hand held GLS inspection lamps. The pits were heated by gas fired hot water radiators. Overhead gas tube radiators were suspended from the roof to provide general heating. A 5 h.p. air compressor was present and in constant use, and a Bus wash (like a giant car wash) was in use a large part of the time.

It was apparent that people on the shop floor new what the problems were, and were technically competent to sort them out, but it was nobodies job to do anything about it so nothing got done. There also seemed to be a fatalistic opinion that management wouldn't take their suggestions seriously. It was surprising that individuals didn't unofficially do things to make life easier and more comfortable for themselves, e.g. fit wooden duckboards in the inspection pits .

The following recommendations were made:

Admin Block: Draught-strip doors and windows. Deepen the entrance lobby to allow the doors to shut easily. Fit loft insulation. Fix the faulty thermostat and reset the room temperature to 19°C. Balance the radiators. Fit TSRVs in rooms which are much to warm or cold. If control was still found to be inadequate, split the heating circuit and zone the building. Clean the luminaires and replace ageing or poorly designed fittings. Replace GLS bulbs with compact fluorescents, and old striplights with slimlines.

Workshops: Block the exhaust ports in the inspection area doors. Clear the oil drums and other debris to allow the draught curtain to close properly. Prevent people over-riding the thermostats. Fit flaps or louvres to the extractors. Fit brush strip to the external doors, draught proof the internal doors to the paint shop. Curtain off the delivery area with heavyweight PVC sheet. Insulate the steam and condensate lines, lag the hot water tank. Reduce the heated volume by fitting a lightweight, e.g. transparent corrugated PVC, ceiling over work areas where the full height is not needed. Fit destratifiers in areas where the full height is needed. Zone the heating. Replace the ageing steam FCU system with a more efficient heating system and reposition to suit current requirements. Improve routine maintenance. Reposition luminaires, replace 300 W GLS with Sodium and Fluorescents as appropriate. Replace other GLS and 38 mm fluorescents with compact fluorescents and ES slimline fluorescent strips. Regulate compressor to suit demand, and fix any leaks.

Garage 2: Curtain the area of the inspection pits. Line the concrete pit walls with insulation board and fit wooden boarding over the concrete floor to improve working conditions in cold weather. Paint the grey walls white to improve illumination. Replace the general lighting fluorescents with the high pressure sodium lamps from Garage 1 (which is to be converted).

General: Promote energy awareness. Monitoring and targeting. Improve maintenance. Investigate the potential for CHP when replacing the existing heating system, because the bus servicing and cleaning mainly take place at night giving a fairly high lighting, heating, and hot water requirement. Consider installing a BEMS as part of the site renovation and reconstruction, since improved controls will be required anyway.

6.1.3 A Computer Manufacturer

Possible low cost energy saving measures in the offices of a computer manufacturer were examined at a number of sites.

6.1.3.1 Slough

The UK head office was in a newish building, but even so it's NPI of 402 was poor.

Despite an annual energy spend of over £100,000 they did not check their bills and had been overcharged £1,836.63 for their electricity. It would also have been possible to reduce the supply capacity saving another £1,404.

Improved HVAC control could have saved £3,800 per annum at a total cost of £2,000. Improved DHW control was needed because the temperature was measured as below 60°C, presenting a legionella hazard. The cold water tanks in the loft could also have incubated legionella because of the relatively warm conditions and low throughput (algae was observed to be present in one tank).

Good housekeeping with respect to lighting could have saved about £1,750 from an estimated lighting cost of £11,000 p.a.

6.1.3.2 Glasgow

The client occupied one floor of a four story block, 304 m², heating was supplied as part of the service charge, but electricity was billed direct to the client.

A saving of £180 p.a. was possible by reduced lighting levels in lobbies and corridors. £750 p.a. was saveable by turning off computers when not in use overnight and at week-ends. £216 p.a. was saveable by replacing GLS spotlights in the entrance with compact fluorescents.

Other suggestions made were as follows:

- Improve lighting housekeeping (a number of fluorescents were old and dirty) and controls.
- Ensure the boilers were only heating the premises during the 5 day working week, the landlord has them running 7 days a week on a simple time controller. Consider improved boiler controls[1].
- Re-negotiate the electricity tariff.

6.1.3.3 London

The client occupied half of an 8 story office block, part of the energy cost was included in a service charge, but £20,003 was billed direct. The building was noticeably overheated, and staff complained it was too hot some of the time.

It was estimated that £1,000 p.a. could have been saved by reducing the temperature and setting up M&T on site, £1,200 p.a. could have been saved by reduced lighting levels in some areas (in other areas lighting was inadequate due to old tubes which should have been replaced) and £200 p.a. could have been saved by turning off unnecessary lights. Approximately £7,000 p.a. could have been saved by turning off PCs when not in use. It was also suggested that the air conditioning requirement in the stores should be reassessed.

6.1.3.4 Buckinghamshire

This office had an energy bill about £20,000 p.a. of which it was estimated that £1,870 could have been saved by good housekeeping. The electrical supply capacity could also have been reduced.

6.1.3.5 Birmingham

The NPI was 406, compared to an EEO figure of 310 and above being bad for that type of site. The energy bill was just over £36,000 p.a., £32,500 for electricity and £4,000 for gas. Tariff re-negotiation and metering changes could have saved £2,082 p.a. at a cost of £100.

The building was overheated, setting to recommended levels would have saved £250 p.a. Improved heating controls could have saved £1,000 p.a. at a capital cost of £950 (there was a tendency for the AC and heating to fight each other due to inadequacies in the control system).

Fitting a timer controller to the Air Conditioning would have saved £3,415 p.a. at a capital cost of £600.

It was also suggested that two 2 kW electric radiant heaters be fitted in an intermittently used area. This would not have given any savings but would have improved staff comfort. It was thought that lighting improvements were possible, both in terms of cost and ergonomics, and a specialist survey was recommended.

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[1] In cases like this, where energy is supplied as part of a service charge, there is no incentive for the landlord to make improvements and the tenant is unable to do so.

6.1.4 Richmond Upon Thames College

The college was very keen to establish its environmental credentials, and had been able to obtain money for environmental training courses from the EU Social Fund because the loss of a major local defence industry employer.

Richmond upon Thames College was a large tertiary college with an energy bill exceeding £100,000 per annum. Despite the annual energy costs, there was no energy management and little energy awareness even amongst those directly responsible. The NPI value of 461 rated very poorly against the EEO's recommended value of below 280 for this type of site.

Energy management, plant operation, etc., used to be the responsibility of the local council's engineering department, but the college saw financial savings from opting out of local authority control and running their own affairs. Responsibility for energy at the time of the survey lay with the Estates Surveyor, Peter White, but he was not experienced in the field and was over committed on other tasks. Energy bills were dealt with by Rembray Utilities, a virtual company wholly owned by the college which gave VAT advantages. No-one could say what energy consumption the college had been billed for,[1] and bills were not checked against consumption, previous bills or read meters. No attempt was made to monitor billing, the college simply paid on demand. More surprisingly, the management staff did not keep records of their bills and were unable to suggest who might. Although the meters and BMS were on modems, no-one could provide up to date energy use data, however it was possible to get energy

[1] At different stages of a later meeting PW gave me two completely different figures for the total gas bill for a particular year, when this was pointed out he had to admit that one must be wrong, but couldn't say which.

consumption and billing data for 1994 from the council's engineers who were still apparently logging it[1] at that time.

Gas was supplied via LASER, a consortium set up by local authorities to bulk buy and get the best rates from the suppliers. The supply chain was British Gas → LASAR → Richmond upon Thames Council → Rembray Utilities → Richmond upon Thames College. Tariff analysis showed the LASER deal to be the best obtainable. Electricity supplies had been switched from Northern Electric to South Eastern Electric, giving a 12.5 % cost saving.

Peter White was pleased that not only had the cost of gas per therm been cut, but the overall consumption had dropped by nearly a third since he had taken charge, so he resented suggestions that energy management on site was poor. Suspicions were raised by this, because there were no obvious attempts at energy efficiency and many obvious areas of wastage. Furthermore there had been no changes of site use, structure, or plant during that period. On investigation two gas meters were discovered which had not been read since the opt-out from council control, and that the council had records of 6 gas meters but the college were only paying for four. It turned out that the Sports Hall and Music Centre annexes had been forgotten about when the supply contract was changed, so a large amount of gas had not been paid for. It is surprising that this had not been picked up by the gas infrastructure suppliers, Transco.

Heating was by gas fired boilers and hot water radiators, there were calorifiers for DHW. In addition to the main boiler room there was a self-contained gas fired

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[1] unofficially, because they expected problems and wanted to make life easier if called in to sort it out, unfortunately it later transpired that much of the monthly consumption data they had was in fact estimated.

domestic central heating system for the "quiet area", formerly a quadrangle which has been floored and roofed over to convert it into a large reading and quiet study room. The boiler for this was in a cupboard off the room and there was concern about the lack of ventilation[1].

The main heating system was fitted with a Landis and Gyr BMS, but this was disabled with all switches turned to manual and the main water mixing valve deliberately jammed in position with an old plumbing fitting. When questioned about this Peter White said that there had been problems with the council over plant control and maintenance, he could not rely on the council engineers and was unhappy with the way the BMS had operated under their control. Since no-one on site new how to run it they had turned off the BMS and control was provided manually by Mr George Cook, plumber and Head of Maintenance. To quote, "George turns it on when he gets up in the morning, so that it's warmed up by the time people arrive, then in the evening he turns it off again. If it's too cold he turns it up a bit, and if it's too hot he turns it down a bit. It's much better than the computerised system because he's here and you can talk to him when you want something done[2]" This didn't tally with experience, the building was overheated and windows and doors were left open to shed heat. Even in mid-winter, room temperatures averaged 23°C and even the entrance corridor was at 19.8 °C. When maximum / minimum thermometers were left in the building over the three week Christmas break it was found that the minimum room temperature was 18 °C[1], despite sub zero external temperatures. From this and observations at the college it was

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[1] apart from any safety aspect the room was stuffy and uncomfortable.

[2] If you can find him. It can be very difficult to pin down a semi autonomous member of staff who has the run of a large site.

the concluded that George probably turned on the heating in October and turned it off in May. He may well have occasionally adjusted the boiler settings, but these boilers were designed to be switched in as needed, with individual boilers optimally running at nearly full load. If this type of boiler is simply turned down, acid gases condense in the flue and the condensate runs down leading to corrosion of the back of the boiler. Three major boiler failures had occurred in recent years leading to the provision of new boilers funded by central government through the "Hunters" programme[2]. Site personnel could say what had failed in the old boilers. Although it is impossible to say why the original boilers failed, if operation in the manner used for their replacements would probably have halved their service life. There were no records beyond the bare minimum[3] required by the insurance company, no set procedures, no gas checks, and no planned or routine maintenance. There was a strong smell of gas in at least two of the gas meter houses, which was reported but no immediate action was taken by the college.

It had been decided that maintenance contracts were too expensive, so the approach adopted was maintenance on failure. This was particularly unfortunate with regard to the Landis and Gyr control system which had an extremely favourable maintenance contract with free upgrading included. The energy audit team arranged for Morgan Rudd from Landis and Gyr and an engineer from the local authority's energy management team to visit unofficially and check the systems. They reported that there was no problem with reinstating the BMS, and that the local authority engineers would

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[1] BSRIA recommends 17°C for *occupied* classrooms.

[2] The Hunters programme also paid for double glazing to be fitted, which we would not have made a high priority.

[3] Medium pressure boiler test records required by Zurich Insurance Co.

be happy to help run the system "if a serious request was made for their services", apparently they felt they'd been messed around by the college in the past.

There was no inventory of equipment which could be used to record any repairs or tests (and could help identify failing equipment before total breakdown). Electrical systems were similarly neglected, only being checked when repairs are carried out and with no routine maintenance. Wiring in certain parts of the college appeared to have very old vulcanised rubber insulation, and should have been replaced for health and safety reasons.

Water systems probably suffered the same neglect, but were not investigated. An earlier engineers report[1] had noted that the water tanks were in poor condition with considerable risk of contamination. It was noted that the sole precaution taken against legionella was that the showers were run every morning to flush them through. As such, it is likely that the system maintenance would have come under attack if there were an incident.

Lighting was generally 38 mm fluorescent tubes, with some GLS. Both could have been cost effectively replaced with more efficient alternatives. The fluorescents were replaced on failure rather than under a routine maintenance programme. Lights were left on when not in use, occasionally in some rooms over holiday periods.

It was concluded that Richmond upon Thames College had:

- No energy policy.

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[1] Adrian Brooks

- No energy management, nor any formal delegation of responsibility for energy consumption.
- No culture of energy awareness, even amongst those responsible for energy on site.
- No communication with users.
- No information systems for recording or communicating energy related information.
- No accounting for energy consumption.
- No financial scrutiny.
- No promotion of energy efficiency.
- No concern about wastage.
- No investment in increasing energy efficiency.
- Inadequate understanding of plant and systems.
- Inadequate understanding of basic energy management procedures.
- Inadequate health and safety procedures[1].

Reference to the EEO's Best Practice publications rates RUTC's energy management as zero on all counts. It was recommended that:

[1] At one point they had even made their Health & Safety officer redundant to save money, until it was pointed out that he was a legal requirement.

- An appropriately senior member of staff should be made responsible, and accountable, for all aspects of energy management. He should be given the time, training, and resources to do the job.

- An energy management system along the lines of BS 7750 should be set up. The cost of this should be justified by predicted low/no cost savings of over £50,000 per annum.

- A member of staff should be made responsible for taking and recording meter readings at monthly, or even weekly, intervals. If possible, the modems should be used to automatically read the meters into a database at the end of each month.

- Immediate remedial measures should be taken to improve energy efficiency, including an overhaul of all plant and controls and staff training to use them

- The BMS should be reinstated, with control by the council's engineering department.

- The heating system should be regulated properly rather than overheating the building and dumping excess heat through open doors and windows.

- A college wide energy efficiency drive should be undertaken, to identify areas of wastage and increase awareness amongst staff and students.

- The old fluorescent tubes and GLS bulbs should be replaced with more efficient alternatives as part of a routine maintenance programme.

- The college should get on ETSU and BRE mailing lists and obtain any relevent publications. For example, subscribe to *Energy Management*, and get two or three copies - one for the energy manager, one for circulation to other staff, and one for the library.
- The gas leaks should be fixed.

During the investigation of the site it was found to be impossible to get accurate consumption data from the college. To assist them in record keeping a set of paper record forms, and later a Windows Paradox data base, were created for the recording of meter readings, degree days, air temperatures, etc. Although intended for the maintenance staff, the computer based system was never used except by students studying on the Energy Management and Eco- Design courses.

The Landis & Gyr BMS was reinstated and the boilers serviced. Temperatures were reduced and there were less doors and windows left open. Some departments were fairly diligent in turning lights off, though this was usually at the initiative of particular staff members rather than a college wide policy.

The electrical wiring was renovated under Hunter programme funding, and the water tanks were also to be renovated.

6.1.5 RUTC Sports Hall & Richmond Music Centre

The sports hall and music centre were two self contained annexes to Richmond Upon Thames College. They had their own heating systems and were independently metered, but unfortunately the meters had been overlooked for a period of time and no consumption data was therefore available.

The sports hall had a low pressure hot water radiator system for the offices and changing rooms, and fan coil units recessed into the walls of the main hall. Calorifiers were present for DHW. The system was generally in fair condition, but there was a broken skylight/window which had been left un-repaired for over a year. Lighting was generally provided by surface mounted fluorescents (38 mm diameter tubes) with diffusers however there were also some GLS lamps in the office and as external bulkhead lights for the entrance walkway. Lights in the main hall and changing rooms were left on when not in use because staff had been told that it cost more to switch fluorescents on and off than to leave them running.

The Music Centre had a gas fired LPHW system for the offices and practice rooms, but a warm air system with steam humidifier for the concert hall. The only complaint from the occupants was that in the summer it was too hot in the practice rooms because traffic noise from the nearby A 316 meant they could not open the double glazed windows. This did not affect the concert hall because the ducted air heating system could also be used for ventilation and cooling. Lighting was similar to the sports hall, but was generally turned off when not in use except in the entrance lobby and main corridor.

It was recommended that the broken window in the sports hall be replaced (as it was effectively a hole in the roof letting heat out), and that someone start taking regular meter readings. It was also recommended that the existing fluorescent tubes and GLS bulbs be replaced with more efficient modern alternatives.

6.1.6 Saints Mary's & Peter's School

St Mary's & Peter's was a small primary school for 185 pupils. It was originally put up as a temporary single story prefab in the 1960's, but has since been upgraded to a more permanent structure. The headmistress thought that she had full gas and electricity records for at least a year, but these turned out to be incomplete. Some of the figures also appeared to be estimates rather than true meter readings.

The walls were made up of insulated brick cavity wall and insulated panels, about 40% of the wall area was double glazed window. The flat roof had recently been refurbished and insulated.

A particular feature was the large number of external doors for such a small building, three main entrances and doors from each classroom to the playground. Draught-stripping had originally been fitted but had worn away. At lunch and break times all of these doors were used and left open, even in winter, because it was thought safer than having children continuously slamming them open and shut as they ran round the site.

Space heating was by gas fired boilers and LPHW radiators with a water temperature of 70°C, with a separate gas water heater for washing. The temperature gauge on one of the 4 boilers was stuck, but the system was generally in fair condition. There were additional convector heaters in the main hall.

The building U Value was calculated to be 0.68, with NPI values of 170 and 144 calculated for the school years 1994/5 and 1995/6. The difference in NPI values may be due to refurbishment of the roof, or simply a result of the errors inherent in energy management. In any case both figures fell within the EEO recommended values for that type of site[1].

Internal lighting was almost entirely by 38 mm diameter fluorescent tubes, with only four GLS bulbs (used in the staff corridor). There was also external security lighting. The fittings were often dirty and some of the tubes were flickering, indicating that they were close to failure and not working efficiently.

No large energy saving investments were recommended, but it was suggested that the lighting should be replaced on a rolling basis by more efficient modern equivalents and the draught strip replaced as part of routine maintenance. If further work were being done on the roof or glazing it would have been worth looking at double glazing the large skylight in the infant school lobby.

Better record keeping was recommended, and that the school take it's own meter readings rather than rely on the utility companies to bill them correctly.

It was recommended that energy awareness be promoted, and it was estimated that at least £280 and up to £600 p.a. could be save by good housekeeping measures. These could have formed part of the children's educational activities.

6.1.7 Saint Vincent's School

For energy and environmental management St Vincent's was unusually good. This was due to the interest of the former headmaster, Kevin Gallagher, and the continuing

[1] less than 137 exceptionally good, over 189 bad, anything between is average/OK.

interest of the current headmistress, Ann O'Sullivan, who in turn has passed it on to other staff. The NPI value was an exceptionally good 113, and the U value 1.02.

The school had nearly complete monthly electricity meter readings, bimonthly gas readings, and quarterly water meter readings, which they monitored and checked for themselves. The Staff Area was separately metered and they only had quarterly electricity consumption figures for this section. The only failing in their system was that it sprang from checking that the figures were correct on the bills they received, so if a bill gave quarterly figures they only checked those figures on the meter. It was recommended that they take their own readings of all meters once a month.

Financial management and routine maintenance were good, and there was a fair amount of energy awareness despite children leaving doors open faster than the teachers could shut them. Water conservation measures had also been implemented. In energy terms they were hampered by having as chairman of the governors a local electrical contractor who donates electrical heating equipment, but in financial terms they were probably still winning. The main space heating and DHW system was gas fired central heating, but there were electric fan heaters, oil filled electric radiators, and electric storage heaters in various parts of the site.

Internal temperature was set at 19°C, with heating on from 7 am to 2 pm, or 3 pm in colder weather. During two weeks of exceptionally cold weather the temperature had been turned up to 21 °C and heating run 24 hours a day. The control system was poor, and some areas could be too cold while others were overheated with windows open to shed the excess.

Lighting had nearly all been converted to 22 mm ES tubes and compact fluorescents, and the rest was being replaced under their routine maintenance plan.

The only thing that can be said is that the staff were enthusiastic and capable, but untrained. When they heard of something useful they tried it, but when unhappy about something they backed down from confrontation because they were unsure of themselves.

6.1.8 Fishmongers Hall, London & St Margaret's School, Bushey

The information on these sites was brought in by students on the RUTC energy course through contacts they had with RTJ Environmental Services[1]. A brief and unofficial survey was made of both sites from the outside to get an idea of what they were like, and the information gathered worked through with the students, but it was their project and all their own work. It was possible to use some of the data for testing programme modules such as the NPI and U Value calculators.

Fishmongers Hall was a listed building and ancient monument dating to the early 19th century, it fulfilled a number of functions covering offices, committee meetings, dining, and entertainment. It was able to provide a full set of monthly Gas and Electricity bills, and they provided these for three consecutive years.

St Margaret's school was an independent school for girls from 7 to 18 years, including day pupils and boarders, it comprised a number of buildings dating from 1897 to the present. Some of the school buildings were heated by oil fired boilers and others of similar age and construction by gas fired boilers, much of the heating system had reached the end of it's useful life. The school was able to provide monthly oil and electricity consumption figures, and quarterly gas consumptions from which monthly gas consumptions were estimated. However, these could not be relied upon as a number of the figures we were given as meter readings turned out to be estimates when the bills were examined.

6.1.9 Hampton Theatre

Hampton Theatre was a new building. It is a £1M+ purpose built structure to house a local amateur dramatic group. The building was an empty shell so it was impossible to do more than give some general ideas about energy management. A Delphi database was created for storing gas and electricity meter readings, which later developed into the meter reading section of the Energy Management programme. The project was passed on to David Eliot, an architect who ran the Eco-Design course at RUTC, and his architecture students. They gave useful input into setting up the theatre internally, interior design, lighting, etc.

6.2 Energy management in theory and in practice.

Despite the variety in types of building and activity on site the sites visited nearly all had one important feature in common. They could not provide sufficient information on energy consumption for a full analysis to be made, and often what information they had was inaccurate. This is probably representative of poorly managed sites, because enquiries through the local chamber of commerce, environmental groups, and education services, and advertisements in the local press over five years looking for suitable test

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[1] It is understood that the energy audit had been carried out following the CIBSE manual AM5:1991.

sites which could provide the necessary data for an energy audit by students of Richmond Upon Thames College, were unsuccessful. Even when the local council energy managers offered a couple of sites for students to survey, they found that they didn't have the necessary energy consumption data to do a detailed audit, only annual readings and some monthly estimates. This experience has been confirmed by a 1993 BRECSU study "Organisational Aspects of Energy Management" which found that 90% of those companies attempting to set up a Monitoring & Targeting programme were unable to effectively do so *despite a £10M investment in promoting Monitoring and Targeting by the EEO.*

Allan Williams of McKinnon and Clarke, reviewing the EEO's 'Practical Energy Saving Guide for Smaller Businesses' for ESTA in 1993, cites the case of a London Hotel which started logging oil deliveries to it's boiler house. This cut costs by 70%, they'd been paying for fuel they had never received. In another case a local authority paid someone else's electricity bill for 20 years.

This lack of energy accountability creates a problem. Step One in the energy management of a site is, theoretically, to do an audit of the energy inputs, outputs, and throughputs for a representative year. In fact Step One should be to establish clear responsibilities and lines of communication. On many sites no-one seems to be responsible for energy management, with lower level energy related tasks divided between people who don't know the overall picture, don't communicate with each other, and often don't know who else is involved.

The fragmentation of responsibility for energy management means that:

- Energy management is always a diversion from more important things in the opinion of the people involved, so it never gets done properly.

- No-one involved ever really knows what is going on.

To carry out an audit usable representative data for the site is needed. Sites which can provide such information are probably already carrying out reasonable energy management practices, because those responsible are interested enough to log their energy usage. In contrast, those sites in most need of energy management are least likely to have the information available for it.

A lack of interest in energy management is not limited to poor record keeping. On such sites there is often no clear allocation of responsibility and authority, poor maintenance, and a lack of understanding and training. These are more than failures in energy management, they are failures of management. The poor energy management is a symptom of a general lack of competent and effective management.

Nigel Pratten at ETSU says that one of the biggest problems they face when trying to promote energy management to industry is the fact that, typically, the energy bill may be only 3% of the company's turnover[1]. Senior management think that the energy bill is trivial and don't concern themselves with it, so nor does anyone else in the company. This shows itself in some of the following ways:

- The necessary structures and procedures are not put in place.

[1] One tactic here is to say that poor energy management is a symptom of poor management, and a 40% waste of energy almost certainly indicates some related wastage of materials, water, manpower, or capital investment.

- Investment in adequate training and manpower is not made.
- There is no, or poor, routine maintenance.
- There is inadequate record keeping, some times even where it is required for insurance or health and safety purposes.
- The responsibility for various energy related functions such as purchasing, systems, accounts, planning, plant, operation and maintenance, investment, etc., may be divided between a number of departments and people. Even if there is adequate communication between departments, no-one really has an overview of what's happening, and no-one really knows or understands what's going on.
- Responsibility for energy is dumped on someone who is already overloaded with work, and he probably considers his other work too important to waste much time learning about energy management. He'll do it when he gets round to it, if something else doesn't come up.
- Responsibility is given to someone generally regarded as too ineffectual to be trusted with more important work, and he can then be ignored.
- Responsibility is given to someone without the authority or standing to make changes.
- Responsibility is given to someone without the necessary training and skills to do the job properly, so they just carry on doing what's always been done.

This is the type of company which is most likely to either buy a low cost energy management package, or to approach an energy management consultant. They do not care about the energy, they want to save money. They will only try being energy efficient if it can save money and does not disrupt things too much or require a lot of extra work.

6.3 Design Philosophy

6.3.1 Encourage The Client

The underlying problems with promoting energy management to business are reluctance to spend money, reluctance to make changes, and uncertainty. For energy management to be taken up the resulting inertia has to be overcome.

Reluctance to spend money can be reduced by showing that a small amount of expenditure now will result in a worthwhile pay-back within a fairly short time. I.e., that any money spent is an investment that will not tie up capital for very long, and will effectively result in an ongoing profit. This approach was publicised by Robert Jones[1], in his question to industry "What extra sales would you have to generate to produce the same increase in profit as a 10% energy saving?" In reply GEC found that every pound of energy costs saved made a net profit contribution equivalent to £10 worth of sales, but without the attendant costs of capturing that business.

Similarly, if changes can be shown to be non-disruptive, profitable, or improve overall management efficiency, reluctance to make them may be overcome. There will always be opposition from some people who feel their position threatened or fear an increased workload, and this should be born in mind.

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[1] Then Minister for Energy Efficiency, quoted in 'Energy Management', Jan 1997.

Often there are staff who would like to make improvements but either don't know how, or lack the confidence to do so even when the solution is obvious. Most low cost energy management is common sense, which any technically oriented person within the company could take care of. Consultants are often used to give a stamp of approval to ideas which people already had, providing reassurance as well as specialist technical detail. A consultant's report can also give useful leverage to someone within the company trying to bring in changes against opposition.

The energy management programme will help overcome these problems by providing a simple tool for the energy manager to carry out routine energy management tasks based upon best practice, thus reducing the time and cost involved in energy management. It will also encourage the client sites to adopt appropriate management and record keeping procedures[1].

[1] E.g. If the site manager is asked "when were the boilers last serviced, we need it for the energy management" they are forced to find out, and to keep proper records in future.

6.3.2 Data Selection & Reduction

"So far as the laws of mathematics refer to reality, they are not certain and so far as they are certain, they do not refer to reality."

- Albert Einstein[1]

"Figures like 97.63 and 48.29 are comforting because although we may not know what they mean, they are at least precise"

- Ehrenberg

There are a number of high powered computer programmes which produce exhaustive analyses of vast amounts of data. Often the precision of the theoretical model bears no relation to the imprecision and flexibility of the real-world situation. In addition the amount of data gathering and processing may not be justified by the degree of accuracy needed, an aspect of the law of diminishing returns.

Ehrenberg gives the following useful illustration of data reduction.

Target Figure = 21,742

Rounded figure	Loss in accuracy
21,740	0.01%
21,700	0.2%
21,000	3.4%
22,000	1%

[1] Geometry and Experience

The pointlessness of wasting time, therefore manpower, therefore money, on attempting high degrees of accuracy in energy management is shown by a recent study published in the United States and quoted in Energy in Buildings and Industry, Jan 1997.

> *"Even when they have identified a measure, fewer than one in six of consultant's estimates come within 20 per cent of the energy savings actually achieved, either way."*
>
> *- Peter Harris*

Data costs money. It costs money to acquire it, and it costs money to process it. There comes a point where the possible gains from having the data are outweighed by the costs of getting and processing it. The inability to accurately assess the effect of many major factors in building energy use makes high precision in other areas redundant. For example, there is little point measuring air temperature to 3 decimal places if you can only estimate that the infiltration rate is between 2 and 5 air changes per hour. The inaccuracy from taking temperatures to one decimal place is insignificant compared to the other errors in the system.

The philosophy behind the energy management package is to minimise the amount of data acquisition, and by sparse data analysis techniques to infer generally usable results about building energy usage. In this way the major areas of possible energy saving are identified, which can then be examined in detail by the energy manager[1] or by specialist contractors.

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[1] much as an energy survey and audit highlights areas for more detailed examination by specialists, such as lighting design, CHP potential, etc.

For example, the system may indicate a high infiltration loss, this could be due to inadequate draught stripping, but it could also be due to extractor fans in a paint-shop, or some similar cause. It would be impractical to try and define all possible variations of all possible variables within the computer program, but it can indicate to the human energy manager where to look for savings.

Related to the philosophy of minimising unnecessary data processing, where an increase in the usefulness of the information is unlikely to result, is the use of a steady state model rather than a transient model for the energy flows through the building. This is supported by the findings of Delorme[1], that dynamic effects are not significant when dealing with long term predictions, and has been accepted in previous work[2] as justification for the steady-state model when analysing building energy usage. A transient response model may be useful for fine tuning a building that is already well managed and accurately monitored, e.g. by a building energy management system, or for designing a new building, but it is likely to be a pointless exercise for the intended market of sites which exhibit poor energy management.

Peter Harris, MD of Cheriton Technology Management says that, from his research, buildings with heating systems operating under optimal start control systems produce straight line relationships between heating energy and degree days, but simple on - off timer control systems give a slight curvature to the graph *which is just detectable with good quality data.* In other words, transient effects will be insignificant in the analysis of energy signatures for typical client sites.

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[1] CIT 1980

[2] J Dorling PhD thesis 1989

7. THE ENERGY MANAGEMENT SYSTEM

A practical and widely applicable approach to low cost energy management was established as a paper based system, around which the computer based energy management system was developed. Two problems were frequently encountered.

Problem 1: If only 20 - 25%[1] of energy surveys result in worthwhile savings, why should the client undertake one?

There is a need to identify which sites are likely to offer significant energy saving opportunities very early in the assessment process. Of course it is often easy to see obvious wastage by visiting the site, and roughly estimate the associated costs. However, site visits take time and cost money, and site managers may expect a visiting consultant to try and talk up the problem and create work for themselves. The solution decided upon is to use Normalised Performance Indicators to compare the energy usage on a particular site to the energy used on a typical site of the same kind.

Normalised Performance Indicators (NPI) are ranges of energy input per unit area or volume based upon statistical surveys of various types of buildings by the Building Research Establishment, with compensating factors for weather conditions, exposure, occupancy, etc., (though a fair approximation is given simply by energy input per unit area). The NPI figures allow, for example, the energy performance of a particular infant school to be compared against the mean performance for a large sample of similar infant school sites. Further, the BRE gives typical NPI figures for good and poor levels of performance. They recommend that a site falling into the bad category should take some energy saving measures.

By using the NPI as a yardstick it is possible to place a particular site in the range of performance for that type of site. If it is less (better) than the good figure, it's probably not cost effective to improve the energy efficiency. However, if the site's NPI is greater than the bad figure then there could be some worthwhile energy saving measures.

Taking this a step further, the ratio of the site's NPI against the statistically derived bad NPI value together with the annual energy cost for the site gives an estimate of the possible annual cost savings on the site. If the potential savings justify it, it is then worth doing a site energy survey to identify where worthwhile improvements could be made.

For example, if the site's NPI is 400, and the BRE says anything over 200 is bad, then it should be possible to save half the energy used annually. If the current energy bill is £20,000 per annum it should be possible to save £10,000 by relatively low cost measures, this would make further investigation worthwhile.

It must be stressed here that the estimated savings are not those which it is possible to achieve, but those which should be achievable at low cost. The site is not being compared against the maximum technically achievable, but against what is already being achieved by the majority of similar sites employing generally applicable low cost energy saving measures.

Not only does this method show whether a survey is justified, but it does so in a way that can be shown to be above board, the sceptical site manager can do the sums himself

[1] quoted in "A strange way to celebrate", Peter Harris, Energy in Buildings & Industry, Jan 97

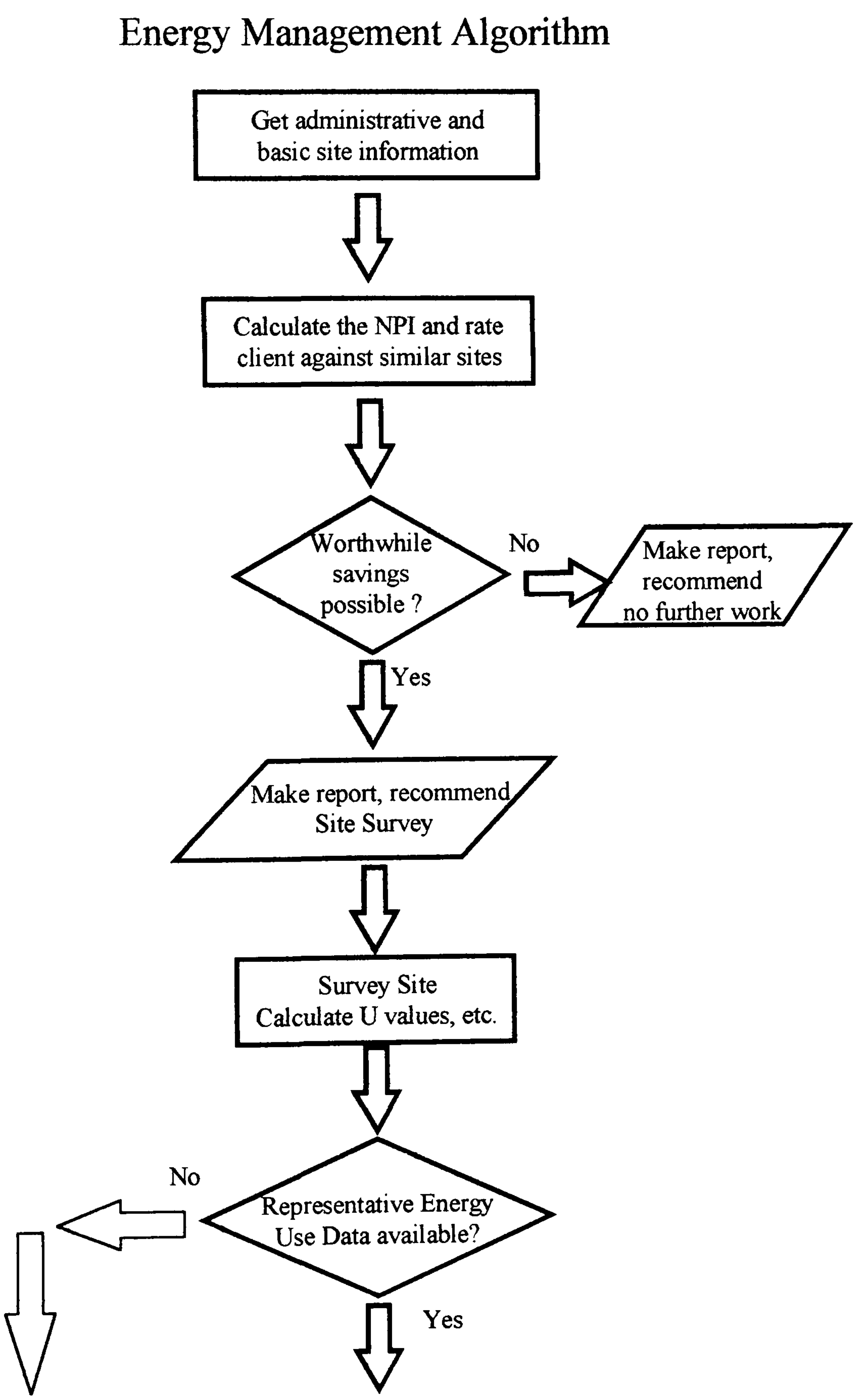
and verify that there is money to be saved by having a survey done and implementing some simple energy efficiency measures.

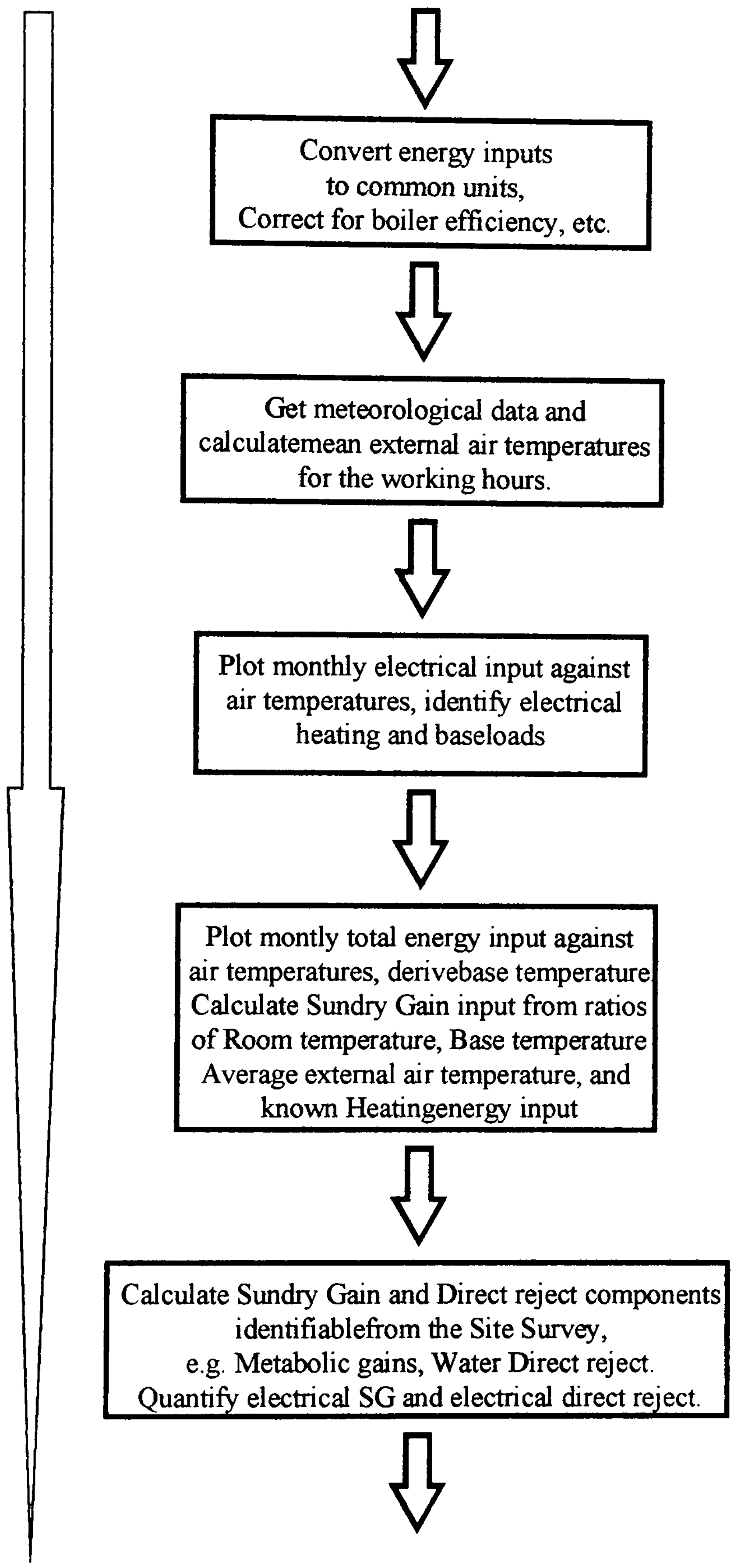
Problem 2. Accurate energy consumption data is unavailable.

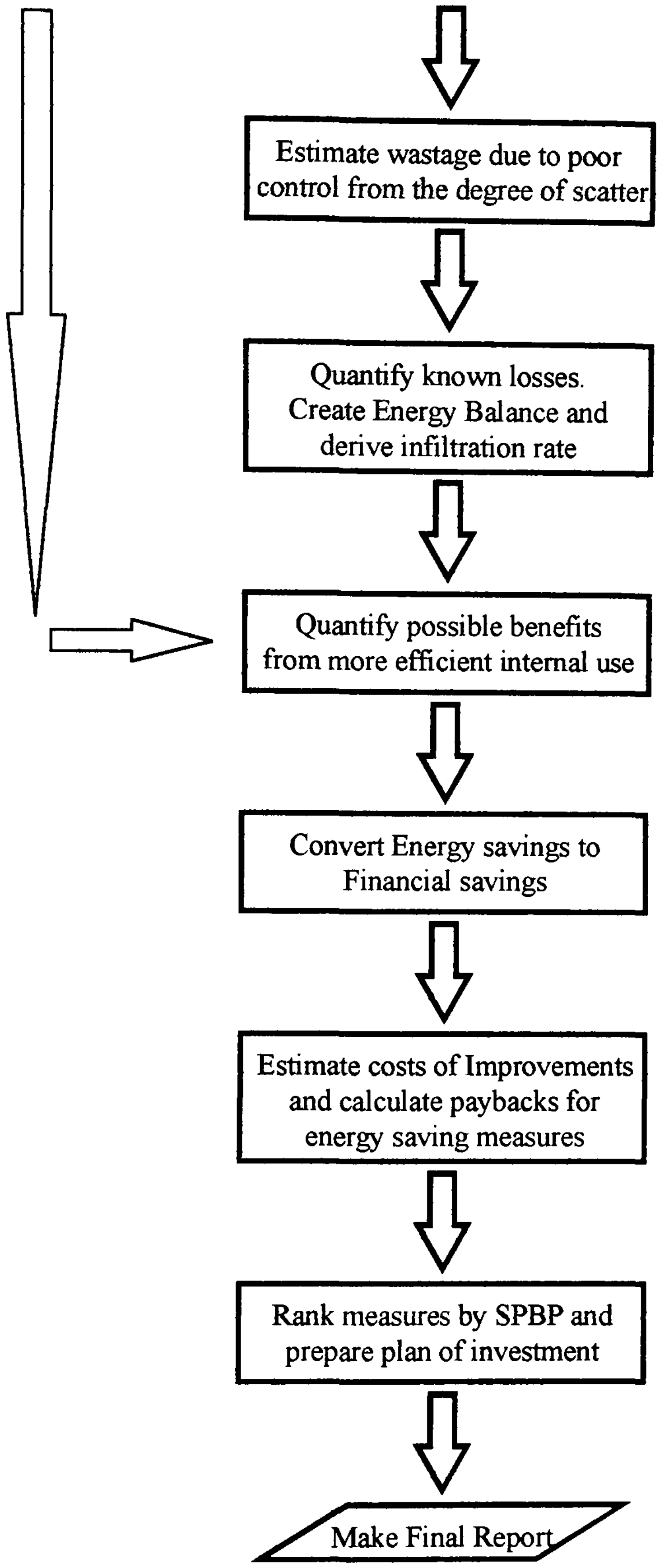
All the best advice is that the first step in energy management of a site should be to carry out an audit of energy use. To do this as recommended by the Best Practice Programme and other standard references, monthly energy consumption figures for a typical year should be correlated against the Degree Days for each month to identify variations from the expected seasonal variation. These anomalies can then be investigated. Energy signature models also correlate energy input against degree days or external temperature, but then infer what the major modifying influences are likely to be. Clearly, a site with inadequate energy management is unlikely to have the necessary energy consumption information. Some may have quarterly information, but very few will have monthly figures. Many sites will not even be able to lay their hands on accurate annual energy consumption figures. Of those that do have quarterly or monthly figures, many of the readings are likely to be estimates rather than true readings. As a result the energy consumption data that is available is likely to be of limited value for an audit.

The most productive course to take in such a case is to conduct a brief survey highlighting obvious deficiencies and provide a management plan suggesting improvements including better energy accounting and the taking of monthly readings by the staff on site. The cyclic, iterative nature of energy management would then mean that the data gathered as a result of these recommendations could be used the next time the energy management procedures were carried out.

7.1 The Energy Management Flow Diagram




Convert energy inputs
to common units,
Correct for boiler efficiency, etc.
Get meteorological data and
calculatemean external air temperatures
for the working hours.
Plot monthly electrical input against
air temperatures, identify electrical
heating and baseloads
Plot montly total energy input against
air temperatures, derivebase temperature
Calculate Sundry Gain input from ratios
of Room temperature, Base temperature
Average external air temperature, and
known Heatingenergy input
Calculate Sundry Gain and Direct reject components
identifiablefrom the Site Survey,
e.g. Metabolic gains, Water Direct reject.
Quantify electrical SG and electrical direct reject.



The following sections set out the requirements of each element of the energy management algorithm.

7.2 Data Collection

Data relevant to the case in question could be directly recorded on a laptop while surveying the site, or could be recorded on paper[1] giving a hard record from which data can later be entered into a computer for processing.

Initially it was envisaged that site data would be recorded on paper questionnaire type forms during site visits, and then entered into the computer when the auditor had returned to the office. Standardisation would simplify the auditing and data entry procedures. Ideally the standard audit forms would be in the same layout as the data input screens. This would be particularly useful if a client administration database were being used for generating site files, as information not necessary to the energy management programme but useful for billing, etc., could be entered.

However, this paper based approach has been outstripped by technology, rapidly falling prices have made lap-top PCs ubiquitous, and it now makes sense to enter the information directly to a computer.

Although paper based forms are now probably redundant, the logic behind the information required is still valid, and the data input screens follow the same logic[2]. Information should be grouped in a logical manner and, where possible, related pieces of information should be stored in the same database table so that it is easily accessed by the energy management or other programmes (minimising the number of tables that

[1] Pro formas for the paper based option are included as an appendix.

[2] Also, the energy management system developed is not restricted to the computer programme. The same procedures could be done manually either as part of a paper-based system or as a training exercise for energy managers.

need to be accessed for an operation improves efficiency and speeds up the programme).

For an energy management tool for general use the most useful data required must be decided upon, and some form of standard questionnaires developed. It is logical to group the data according to the energy related area of use, e.g., lighting, building structure, accounts. Related items of data will hopefully be closely associated in the system, making it easy for the user to keep track of. Staff can be easily questioned during a survey or audit on their own specific areas of responsibility. So questions best answered by the accounts department would not be mixed in with questions about maintenance and lighting can be separated from, say, boilers.

Another objective in designing the forms is to use them to influence client organisations to adopt good energy management practices. In such a manner companies that for example, don't carry out monitoring and targeting, can have a basic structure provided for it and be recommended to do so in future.

Even for the generalised energy management system, which doesn't go into detailed analysis of plant , etc., some 250 to 300 items of site data have, where possible, to be gathered and analysed. Some data is easy to acquire, but some may be difficult or impossible to get on a badly managed site, and all of it requires work, time and money The programme will bring these minimum required pieces of energy related information to the attention of the people responsible for energy management on site. Even if they don't currently have records of, for example monthly fuel consumption, they will have been alerted to the fact and may start keeping them (if they are sufficiently interested).

7.3 The Initial Assessment

An administrative record must be created to identify each new client site. At this point it is not worth creating a full record covering site survey, etc., as the energy audit might not go any further if the potential savings do not warrant it, or the customer may lose interest. The data needed at this point is just enough to identify the site and make a rough estimate of the potential annual savings. The simplest way of estimating the potential saving is by calculating a Normalised Performance Indicator for the site and comparing it against standards for that type of site. If the potential saving warrants it a site survey and analysis of energy use can then be carried out.

7.4 The Site Audit

If the initial assessment suggests that worthwhile savings are possible from simple low and no cost measures a site audit is justified. This involves surveying the site, collating energy consumption and meteorological data, constructing the energy signature and energy balance, estimating possible savings from specific low and no cost measures, and setting out a plan of investment based upon the maximum return on investment.

7.4.1 The Site Survey

Time is money. From a business point of view the site survey should be quick and not too profound, gathering just enough information to make informed recommendations and suggest more in depth investigation of specific areas of interest[1].

7.4.1.1 Energy Management

As well as gathering data about the building and plant use, the site survey allows an impression to be formed of the level of energy awareness on site. This would cover such things as whether doors were left open, lights left on, general standards of maintenance, record keeping, etc.

Ideally there should be one person on site with over all responsibility for energy management, and all other energy related functions should be reported to him, so that someone has an overview of everything to do with energy use on site, whether it is electricity tariffs or boiler maintenance. By asking for people's names to put against energy related tasks clear lines of communication and staff responsibilities are created.

7.4.1.2 Staffing Levels

A knowledge of staffing levels allow an estimate of metabolic gains to be made. e.g. Office Staff 180 watts per person, Manual Staff 270 watts per person.

7.4.1.3 Building Structure

From the structure of components such as walls, roof, doors, and their areas, a U value[1] can be calculated for the building. Since one is unlikely to want to spend time

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[1] For example, if CHP might be an option there is no benefit going into a detailed analysis when suppliers like Meller can come in and give you the benefit of their expertise for free.

measuring walls and counting windows a simplified box model of the building is used, based upon the length of North and West elevations, wall height, plan area, and estimated percentages of N, S, E, and W wall areas taken up by glazing. This seems to work fairly well and the slight loss of accuracy due to the approximation is insignificant compared to uncertainties about other losses.

Building U value = ((Wall Area - Windows Area) x Wall u value[2]
+ (Windows Area) x Windows u value
+ (Doors Area) x Doors u value
+ (Roof Area) x Roof u value
+ (Floor Area) x Floor u value)
/ (Wall height x Length of N elevation x Length of W elevation)

Wall Area = 2 x (Wall height x Length of N elevation x Length of W elevation)
x (100 - Glazing %) / 100

Windows Area = Wall Area x (Glazing % / 100)

Roof Area = Length of N elevation x Length of W elevation

Floor Area = Roof Area

7.4.1.4 Heating Plant

If the heating plant is in good condition[3], well maintained and regularly serviced, the typical efficiency could be looked up in manufacturer's literature, or estimated from standard references, e.g. ASHRAE gives overall efficiency of 92 to 96% for electric boilers, combustion efficiency of 88 to 95% for condensing boilers, 75 to 86% for other

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[1] Measure of the building's impedance to thermal conduction through the fabric.

[2] The u values of components can be looked up or calculated from scratch

[3] Note; boilers<20MW come under Clean Air Act, 20MW < 50MW Environmental Protection Act BATNEEC, >50MW HMIP.

types of mechanically fired boilers. Overall efficiency is lower than combustion efficiency because of radiative losses from the boiler casing, etc.

Although one doesn't want to get tied up with measuring the boiler efficiency, combustion efficiency can be fairly quickly determined by infrared sensor systems or Drager tubes and thermocouples[1]. Overall efficiency is a lot more complicated to determine, and should preferably be left to a specialist[2] if possible.

BS 845 provides the British Standard method for calculating boiler efficiency, which may not be the best and certainly requires more data than is likely to be easily available for a routine energy audit. In the programme this is left as overall efficiency, and can be estimated or calculated by the user depending upon the data available. Most sites are unlikely to provide the data required for BS 845, or want to spend the money on getting it. However a separate tool is provided for doing the BS845 Boiler efficiency calculation procedure where the data is available.

7.4.1.4.1 Boiler efficiency calculation

Of interest is the amount of the energy contained in the fuel which is released into the building. With electric boilers where the boiler room is part of the building this is 100%, but for other cases there will be various losses.

Heat supplied by the fuel

For most purposes the heat supplied can simply be taken as

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[1] Need to know Fuel's calorific value, flue gas temp, %CO (or O2 or CO2).

[2] ETSU typical figure for contract maintenance costs for energy related systems and plant is 0.7p / kWh.

$$Qin/time = QfMf/time$$

where Qin is the heat input to the building, Qf is the calorific value of the fuel and Mf the mass of fuel.

For some liquid fuels where the fuel and air temperatures are very different it may be necessary to make a correction to Qf of $+ 1.92(T_{fuel} - T_{air})$

For gaseous fuels, where the calorific value is usually given in MJ/m3 the heat released is given by

$$Qin/time = V\ Qf$$

Where V is the gas flow rate in m3/s. Calorific values may be converted to kJ/kg by multiplying by 1,000 and dividing by the density of the gas.

There is a possible flow rate correction factor, this time due to the temperature and pressure of the supplied gas.

$$V = Vm(Pa + Pg)288 / 1013(Tg+273)$$

where Vm is the measured flow rate, Pa air pressure, Pg the gas pressure, and Tg the temperature of the gas at the meter.

For the purposes of the energy management system these corrections are assumed to have been taken into account by the fuel supplier when calculating the calorific values. A complete analysis of boiler performance is beyond the scope of the simple energy audit being undertaken.

With solid fuels there is a loss due to unburnt fuel in the ash, dust, etc. This can be calculated using the empirical equation

$$\text{Gross loss} = 33{,}820 \times \text{Mass of ash} \times \%\text{C in ash}$$

However, since it is unlikely that a chemical analysis of the ash is available the EEO's figure of 3% will be taken as typical for this loss.

Stack losses

There are various methods for finding stack losses, the simplest being to hire an electronic meter which will give the combustion efficiency directly from sampling the flue gases. Similarly the efficiency can be found in tables if the flue gas temperature, CO content, etc. are known.

The following equations are based upon those given in BS 845 for the calculation of stack losses. Apparent differences are because ash losses have been taken into account during the calculation of heat energy liberated from the fuel.

Loss due to sensible heat in the flue gases[1]*, L1*

$$L1\ \% = k(T_{\text{flue gas}} - T_{\text{air}})/VCO_2$$

where k is the Siegert constant for the fuel (=255 x %C / Q), and VCO_2 the stoichiometric volume % of CO_2.

Losses due to water vapour in the flue gases, L2

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[1] ASHRAE follows a similar procedure to the British Standard for calculating losses, but seems to make clearer provision for excess air losses in the flue gas loss

$$L2gross\% = (MH_2O+9H)(2{,}488-4.2Tair+2.1Tgas)/Qgross$$

$$L2net\% = (MH_2O+9H)(210-4.2Tair+2.1Tgas)/Qnet$$

Where MH_2O is the % moisture content and H the % hydrogen content of the fuel by weight.

Losses due to unburnt fuel in the flue gases, L3

$$L3gross\% = k1\ Vco/(Vco2 + Vco)$$

$$L3net\% = Lgross\% \times Qgross/\ Qnet$$

Radiative, conductive and convective losses, L4

$$L4 = 6.7\ A1\ (Tk-Ti)\ /\ Qa\ l1 + \quad 53\ A2\ Qa\ \ /\ A\ Qr\ (l2 + 1.3)$$

Where A1 is the boiler exterior surface area backed by water or steam, A2 the area backed by hot gas, A the total external surface area. Tk and Ti are the combustion and water/steam temperatures. Qa is the actual rate of heat input during the test based upon the fuel calorific value, Qr is the heat input at the boilers rated output based upon the fuels calorific value. l1 and l2 are the thicknesses of insulation (l = 0.05 W/m^2K) on the water/steam and gas backed surfaces. If the insulant l is different it must be corrected for by multiplying these thicknesses by 0.05/l.

Typical values for the above calculations

Fuel	k gross	k net	VCO_2	H	k1
Coke	0.75	0.76	20.6	0.4	70
Anthracite	0.67	0.69	19.1	3.0	65
Coal	0.62	0.65	18.4	4.0	63
Fuel Oils, class E,F,G	0.51	0.54	15.8	11.5	54
Fuel Oil class D	0.48	0.51	15.5	13	53
LPG butane	0.43	0.46	14.1	17.2	48
LPG propane	0.42	0.45	13.8	18.2	48
Natural gas	0.35	0.39	11.9	24.4	40

Blowdown loss

Blowdown is the deliberate periodic venting of some of the boiler water to remove minerals and particles which have become concentrated in the boiler due to evaporation of the water carrying them.

From EEO literature, blowdown %loss for a steam boiler is approximately 0.25 x blowdown as percentage of feed water. Typically the blowdown loss is around 2.3%.

If an analysis of the feed water is available the required amount of blowdown can be calculated by use of the following formula:

$$\% \text{ blowdown} = Sf \times 100 / (Sb - Sf)$$

where Sf is the Total Dissolved Solids level in the feed water, and Sb The desired TDS level in the boiler.

Condensate return

As much steam condensate as possible should be returned and mixed with the feed water to raise the temperature of water fed into the boiler (to a maximum of 82°C due to pump cavitation problems). Recycling of condensate will also have the effect of reducing the blowdown required. The condensate/feed tank should be adequately lagged, as should the lines if steam is not simply being used for space heating. If the system is simply for space heating it may still be worth lagging the pipes, e.g. if they run near the ceiling in workshops, garages, etc., they will be supplying heat where it isn't needed.

Steam heating systems will not be included in the computerised system because they in the United Kingdom they are more or less obsolete anywhere outside of hospitals.

7.4.1.4.2 Other Heating systems

Where the heating system uses direct combustion, e.g. gas radiant heaters, the heating input will be the fuel calorific value multiplied by the efficiency of the heater.

Where electrical heating is used, all of the energy is assumed to be converted to heat within the building.

Some sites may be suitable for the introduction of Combined Heat and Power plants, particularly as a replacement for ageing boiler systems.

Based upon ESTA literature, in particular from George Meller Ltd, mini CHP generators are available with outputs from 22 kW to 5 MW for small scale applications. Typically if a site operates for over 5,000 hours a year with annual electricity costs over £5,000 and hot water or low pressure steam heating costs over £3.000 p.a., Meller state that investment in a mini CHP system will save money. If site energy usage approaches or exceeds these figures and existing plant is due for replacement it would be worth getting a feasibility study on installing CHP on site. The EEO says that if a site has a simultaneous requirement for heat and power of over 4,000 hours per year CHP becomes cost effective.

According to Mahmoud Abu-Ebid at ETSU a 25-30% saving in energy cost is possible with Combined Heat and Power. CHP is typically expected to pay for itself in 3 to 5 years[1].

The UK Government has a target of 5,000 MWe installed CHP by the year 2000, 12 - 46 GWe by 2010[2].

7.4.1.4.3 Record keeping

It is worth checking what kind of records are being kept, if any. By asking about the service history and any failures someone is forced to think about keeping records. A

[1] Example - Roche Products, Fareham SPBP 5.46 years, actual payback in 4.7 years according to an audit done by Dr. Ray Nicholson of Thermal Developments Ltd. for ETSU

[2] CHP 1995 ~ 3,500 MWe = 6% of UK electrical generation. - Terry Clarke, Energy and Environmental Unit Manager, Government Office of the South East

recurring failure may indicate misuse of the plant or some other problem with the system.

The enquiry into a disastrous gas explosion in the boiler room of Lambeth's Kerrin Point block of flats found that 10% of the local authority's properties were neither keeping records nor undertaking proper maintenance procedures. This was certainly negligent and may have invalidated their insurance. The enquiry found that the causes of the explosion were faulty installation and poor maintenance. 200 people were left homeless and 11 hospitalised.

7.4.1.5 Controls

Rather than going into a detailed study of the control system, it can be rated against the control bands given in the 1990 Building Regulations1. Start and finish times and room and DHW set temperatures should be recorded for later use in energy loss calculations.

7.4.1.6 Internal Energy Use

Most manufacturing plant, etc., will be too site specific for this programme to predict optimum usage. There are however some areas of energy usage which are widely applicable.

7.4.1.6.1 Lighting

The installed wattage and estimated annual usage of standard lighting types should be estimated, these offer potential savings by low cost replacement with more efficient modern alternatives.

[1] See also Best Practice Programme Fuel Efficiency Booklet 10, Controls and Energy Savings.

When warranted a site could be given a more detailed lighting survey by a specialist contractor.

7.4.1.6.1.1 Standard lighting types[1];

General Lighting Service, GLS

Incandescent filament bulbs, used for general lighting and display. Typical life 1,000 hrs. 8 - 18 lumens/Watt. Lamp cost £0.5 - £3. Luminaire £10.

Tungsten Halogen[1]

Display and floodlighting. Typical life 3,000 h. 18 - 24 lum/W.

Lamp £1, Luminaire £20.

38 mm diameter Fluorescent tubes

Low pressure mercury discharge. (MCF, MCFA, MCFE, MCFR)

General lighting, variations available for specific purposes such as colour rendering. Life to 30% reduction in output typically 5-10,000h. 37-90 lum/W dependant on type, but standard white ~73 lm/W, natural 53 lum/W. Tube £3.40, luminaire £10.

ES 26 mm diameter krypton filled slimlines

90 lumens/W. Direct replacement for standard tubes. life 5-10,000h. Tube £2.40, Luminaire as above.

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[1] Note: Only GLS, halogen, and hf fluorescents have immediate start up, the others take time to come on and are not suited to frequent or short on/off cycling (e.g. in response to PIR sensors).

High frequency argon filled fluorescents.

Need a special high frequency electronic ballast[2], so are not a direct replacement for existing fluorescents. The main advantage is a longer service life than slimline fluorescents for similar performance. 90-100 lm/W, Pritchard quotes 92 lm/W as standard. Tube £5.80, high frequency ballast £32.

Compact fluorescent.

Direct replacement for conventional tungsten filament light bulbs. Life 8,000 h. 70 lm/W. lamp ~£10.

High pressure mercury tungsten discharge.

(MBFT, MBTF)

Long life alternative to GLS in awkward areas. Life 5-8,000h. 10-26 lm/W.

High pressure mercury discharge.

(MBF, MBFR, MBF deluxe)

General industrial lighting, floodlighting. Life 5-10,000 h. 36-54 lm/W. Lamp £7, luminaire £55.

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[1] According to ETSU, tungsten halogen rather than tungsten spotlighting is supposed to give a 30-75% saving at a cost of £15-£30 each.

[2]The EEO give a 15 - 20% saving for high frequency ballasts compared to the same tube with a standard ballast. The hf ballast cost is about 50p per Watt.

EEO estimate that replacing diffusers and louvres with prismatic panels or specular reflectors will give a saving between 20 - 50% at a cost of £20-£50 per luminaire.

Automatic lighting controls are said to give a 20 - 50% saving with a 2 - 5 year SPBP, and localised rather than general lighting a 60 - 80% saving for a 4 - 8 year SPBP.

High pressure mercury discharge, metal halide.

(MBI, MBIF, MBIL)

Industrial and commercial general lighting in high roofed areas, floodlighting. 5-10,000h. 66-84 lum/w. Lamp £15, luminaire £70.

High pressure sodium discharge.

(SON, SON-TD, SON-L, SON-R)

General lighting in industrial and commercial buildings, area floodlighting, SON deluxe used for office up-lighting. Service life to 30% reduction in output 6-12,000h.

Typically 67-121 lm/W. Lamp £25, Luminaire £100.

Low pressure sodium discharge.

(SOX, SLI)

Road lighting, etc., where colour distortion is acceptable. Service life 6-12,000h. 100-175 lm/W.

7.4.1.6.1.2 Recommended Lighting Types

The EEO recommends that the main energy efficient lamp choices are slimline fluorescents, compact fluorescents, and high pressure sodium.

Low energy lamp substitutions for internal lighting			
Existing Lamp	Replacement	Consumption Ratio	Equivalent Cost
GLS	Compact fluorescent	0.25	10/8
GLS Spot	Halogen	0.77	2 (*3)
38 mm fluor.	Slimline tube	0.77	0.6

* plus a proportion of the cost of the luminaire as not direct replacements. Consumption ratio is power for same illumination, Equivalent cost is replacement lamp's cost/life vs. original lamp's service life.

7.4.1.6.1.3 Capital cost of fluorescent luminaires

(for the same illumination level)

38mm fluorescent 77 W tube = £3.80 (tube only)

26mm 70 W ES slimline = £2.40 (tube only)

(£10 for tube, luminair, and ballast)

HF Argon 56w = £5.79 (+HF ballast, £32 in late 80's)

HF Philips Calculux system ~£ 65/luminaire, + £44 amplifier and £38 photodetector (controls 500 luminaires)

The costs and benefits of lamp replacement can be calculated from :

Investment = (Other Costs £/kW + New Lamp Cost £/kW
- (Old Lamp Cost £/kW * New Life h / Old Life h))
* (Old Lm/W / New Lm/W) * Old Installed kW

Other costs being replacement of the entire luminaire, etc., if the new lamp is not a direct replacement of the old one.

kWh/Yr Saved = Old Installed kW -((Old Lm/W / New Lm/W)
* Old Installed kW) * Utilisation h

7.4.1.6.2 Electric Motors

7.4.1.6.2.1 Over-sizing

Electric motors are generally designed to be at their most efficient at or near full load. In practice the average loading has been found to be about 65% of full load, knocking the efficiency of a typical motor down from about 95%[1] to 80%. At 25% of full load the efficiency might be as low as 50%. If a motor is running under steady conditions over-sizing up to 25 - 30 % will only make a small difference to efficiency, but if a motor has to meet occasional peak demands, but generally runs well below full load, it will be very inefficient. Power factor drops off even more quickly than efficiency when running below full load, and this has various associated costs in energy and capital equipment.

7.4.1.6.2.2 Power Factor

Electric coils are inductors and have a lagging power factor when driven by AC power. This applies to heater coils in ovens and furnaces, welding gear and other discharge equipment, transformers and motors. When AC is applied to an inductor there is an induced back electro-motive force which causes the current to lag behind the applied voltage. The power through the coil at any instant is the product of voltage and current at that instant, so for a given motor power a higher current must be supplied to compensate for the phase lag.

DC circuits $P = IV$

AC circuits $P = IV \cos \phi$

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[1] ETSU give 95% as a typical figure for an AC motor at full load, but some designs are much less efficient, say 50%.

where ϕ is the phase lag, and Cos ϕ the power factor. For a pure inductor ϕ would be 90°, but because of capacitive and resistive loads in the circuit the phase lag and power factor will vary from installation to installation.

The apparent power requirement in kVA is thus greater than the true power of the motor in kW, and the ratio of the two is termed the power factor. This higher power requirement means that the electrical supply system has to be designed for a higher load, with associated greater capital costs.

The power factor can be corrected, brought close to unity, by fitting a suitable capacitance across the coil. Capacitors cause current to lead voltage in AC circuits, and so compensate for the inductance of the coil.

Motors are not included in the EMAN programme because the range of types, characteristics, applications, etc., makes general recommendations fairly superficial. To really do something useful would require an in depth analysis of the motors used, the conditions of use, future plans of the company, etc. This is at odds with the low cost, fast pay-back philosophy behind the EMAN programme, and the client is unlikely to do anything about it unless replacing them anyway.

7.4.1.6.3 Compressed Air

Compressed air is used on many light industrial and commercial sites for driving machines and tools, paint spraying, etc. From EEO figures approximately 10% of electrical power used in industry is in the generation of compressed air.

Losses occur due to leaks, use/misuse, distribution, treatment, and generation. Generation, treatment, and distribution are specialist areas dependent on a particular company's present and projected needs, as such they are outside of the scope of this work. Different compressor types, for example, vary widely in efficiency depending on operating pressure and flow volume. Regarding distribution, it is worth noting that for a 250 l/s, 7 bar supply approximately 5 kW is wasted by each 1 bar pressure drop along the line. A 40 mm diameter line gives 1.8 bar pressure drop over 100 m, but an 80 mm diameter line only has 0.04 bar drop, and a 100 mm diameter 0.02 bar per 100 metres. On many sites where systems have evolved rather than been planned the pipe work is 12 or 25 mm diameter steel tubing, usually because that is what was easily available to the maintenance man who fitted it, and he probably had suitable fittings in stock.

The Energy Systems Trade Association literature says that a 10 p.s.i. reduction in delivered pressure in a compressed air system gives a 5 - 7% reduction in power demand.

7.4.1.6.3.1 Leaks

Leakage losses vary from 5% to 70%, with 10% considered good and 30% fairly typical. Leaks are often audible, and can also be found by painting joints with a water/detergent solution. The amount of leakage from the system can be estimated from the cycling of the compressor during periods when there is no demand. When pressure in the reservoir drops below the minimum operating pressure the compressor will switch on, and when the upper set operating pressure is reached it will cut out. With no other demand on the system this work is being done to service the leakage of compressed air from the system. This can be compared with cycling times under normal operating conditions to estimate the percentage loss due to leaks (since it is unlikely that the compressor power consumption is separately metered). Most leaks are fairly inexpensive to repair, often simply requiring the tightening of a joint, but tend to be overlooked unless the cost is pointed out. The site survey can do this by estimating the percentage leakage loss, the energy to service that loss, and the subsequent cost.

7.4.1.6.3.2 Use and Misuse

7 bar is a standard pressure for compressed air systems, so compressors tend to be run at that irrespective of the required pressures at the end of the line. Often this may be only 3 bar. If the compressor were run at 3 bar there would be a 30% direct saving in energy, there would also be a knock on saving in reduced leakage. If this is not possible the compressor should be sited to minimise the distribution drops to high pressure equipment. Although it is fairly straightforward to calculate the work done in compressing a volume of gas, in practice the mechanical and thermal losses of the compressor make theoretical savings and practical savings diverge considerably.

As a rough estimate, if we assume that the compressor is 30% efficient and that the reduction in pressure reduces that 30% in proportion to P1/P2, a reduction from 7 to 6 bar gives 1/7th of 30% ~ 4% improvement.

Where very different pressures are required it may be cost effective to have two separate systems. Compressors are also often left running during periods when there is no demand, this is another easily avoidable waste of power.

7.4.1.6.4 Water Use

The annual water usage, supply drain temperatures can be used to estimate direct reject from warm water flowing out of the building.

7.5 The Site Energy Signature and Energy Balance

7.5.1 Heating Input

The process of collecting heating input data from billing data can be summarised as follows:

- Get monthly fuel (electric, gas, oil) consumptions, costs, and tariffs from bills.
- Confirm that the figures represent actual meter reading and are not simply estimates.
- Convert the monthly consumptions to common units, and normalise the energy inputs based upon man-hours or days worked for each month. This will compensate for holidays, etc., and be representative of the activity level on site.
- Adjust the normalised figures for the boiler inefficiency, to give actual heating inputs to the building for each month.

7.5.2 Tariff analysis

There are a number of problems with including utility tariff analysis within a general energy management program.

With the deregulation of the energy supply industry there has been a growth in "confusion marketing", the proliferation of tariffs, options, discounts, etc., to make direct comparison between competing suppliers difficult. While it is not too difficult to use a spreadsheet to identify the best option among those on offer in a specific case, it is very demanding to include a tariff analyser within a programme for general use, which would have to be flexible enough to deal with all conceivable (and probably a number of unforeseeable) situations. Since software already exists on the market for the specialised purpose of tariff analysis it was not needed within this programme.

7.5.3 Derivation of Monthly Mean External Air Temperatures

7.5.3.1 External Air Temperature

Existing energy management procedures make use of degree day data. This results in an estimate of the heating requirement at a particular site based upon the average conditions of an average site, making no reference to the operating period, etc., of the site. In this way a day shift is treated the same as a night shift, but in fact the external temperature will be quite different. There is thus likely to be a large error in comparing two similar buildings, one of which is used as a school and the other as a night club, a church and a cinema, or an office and a hostel.

At the other extreme, electronic Building Energy Management Systems continuously survey and analyse actual conditions at a particular site. A site with such a system installed is probably already being effectively managed, and is unlikely to need another energy management package.

The method employed here attempts to fill the gap between the two approaches, by giving fairly accurate information about conditions related to a particular site without the investment in time, effort, or money necessary to log the information on site.

Air temperature is influenced by many variables, but tends to follow a characteristic diurnal curve and tends to average out over a number of days. This is convenient because the fuel consumptions for a site should be available in terms of monthly bills[1].

If we accept that for buildings generally the time spent heating the building up to working temperature at the start of the day, and cooling down at the end, are short compared with the heating period, and in addition that thermal mass is likely to have a small effect compared to other losses, then transient effects can be ignored.

In this way, since the thermal ramp up at the start of the shift is equivalent to the ramp down when the heating system is turned off it can just as well be treated as an instantaneous rise and fall in internal temperature at the start and end of the heating period. Although an approximation, the errors resulting from this approach are relatively small[2].

On this basis, the monthly heating energy input can be directly related to the mean external air temperature during operation. The effective external temperature can be found by generating the diurnal temperature curve and then averaging between the start and finish times. This requires the mean maximum and minimum temperatures, start and finish times, and times of dawn and dusk for the month in question.

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[1] Note: This is not necessarily so, figures are often based on estimates rather than actual meter readings. Where the figures are taken, they may not be properly kept, so that monthly data is lumped together to give an annual figure and the original records lost. In this way the energy signature may be thrown by deceptively accurate seeming monthly data which is in fact simply someone's guess.

[2] This wouldn't hold for a well insulated, sealed, heavy, etc. building, but we're not likely to be using this programme on such a site

7.5.3.2 Temperature data

Suitable site temperature data is unlikely to be available, but can be estimated from conditions at nearby meteorological stations. Temperature data is readily available from two sources, the Met Office and weather reports in the press. Of these the Met Office is a better source because it offers a large number of sites, and monthly averaged data, so reducing the amount of data collection and processing required to give a useful answer.

If press reports were used, daily information for met stations would have to be collected and averaged over the month. It would be possible to reduce the amount of data acquisition and processing by treating the stations as an array in which, say, a third are sampled each day. e.g., if there are six sites on a line, stations 1 and 4 would be sampled the first day, 2 and 5 the second, 3 and 6 the third, 1 and 4 the fourth, etc. This would rely on persistence effects and the relatively close spacing of met stations in the UK to smooth out errors and give representative temperatures for a site over the month.

Met office data sheets also provide useful information such as altitude, average wind speed and direction, etc. Altitude is important since met data is standardised to sea level equivalents, so there will be an altitude correction factor in the interpolation of 0.6°C per 100 metres above sea level.

On the negative side, Met Office data must be paid for while newspapers are effectively free via libraries. This would create a significant investment cost if large numbers of sites were paid for at commercial rates.

7.5.3.3 Method Of External Air Temperature Estimation

Temperature across the British Isles does not vary smoothly, though over a short range it can form a fairly regular field, i.e. vary fairly smoothly and predictably.

It would be possible to take weather data from all UK met stations as nodes in a finite element network, but this is unlikely to be accurate because of the lack of long range regularity. Such an approach would also require a large amount of data gathering and processing, incurring high costs which would probably not be justified.

Because this approach is inappropriate to the objective of minimising data a method of estimating the temperature on a site from a small number of nearby known data points was called for.

7.5.3.4 Fuzzy Logic

Originally development of a "human like" routine for estimating temperatures was attempted. The underlying philosophy was that the probability of having the same temperature at two points will be related to the similarity between the points. When there is zero separation, i.e. both points are at the same location, the similarity is 100% and the probability of them having the same temperature is 100%. As the points are separated they become less similar, so the probability of them having the same temperature drops (the probability, not the actual temperature). This is easiest to visualise as a “probability well” formed by the known point. As you move away from the known point you move up the side of the well and the probability of having the same temperature decreases, though you may in fact still have the same temperature. The country could then be seen as a surface puckered with probability wells around meteorological stations, and any point in the country would have a most probable temperature resulting from its position relative to these known points.

The "best guess" temperature would be the result of taking a number of estimates based on nearby met station temperatures and weighting them by distance (i.e. by probability of the same temperature occurring) to give a weighted average.

$L_{1..3}$ = (Distance 1 + Distance 2 + Distance 3) / Distance $_{1..3}$

Weighted average = ((L_1x Value $_1$)+ (L_2x Value $_2$)+ (L_3x Value $_3$))/ ($L_1 + L_2 + L_3$)

A disadvantage with this method is that if the nearest known data all came from the same general direction one would not be able to allow for trends. For example, if the temperature was dropping from west to east and the site was to the west of the met stations used, then a low estimate would result. To overcome this by forcing the use of data from met stations in different quadrants around the site would result in using data from more distant, so less similar, locations.

It was then attempted to develop a "virtual surface" method to improve upon the weighted average, but it was found that this method tended to give wild results when the client site was close to the meteorological stations. For this reason, the weighted average method will continue to be used because it gives reliable results with an acceptable level of accuracy.

7.5.3.5 Correlation Of Energy Input Against External Temperatures.

Either get monthly degree day or monthly air temperature data for the site, and calculate mean external temperatures for the site for each month and for the year. If using air temperatures, a diurnal temperature curve can be constructed and chopped at the start and finish times of the heated period to give a mean external temperature during the working hours rather than for the whole 24 hour period.

Use Gaussian regression or a graphical method to correlate electrical input against temperature to identify electrical heating, base load and maximum demand (if this is substantially below the contracted figure it may be possible to re-negotiate the tariffs and save some money, if above it may be necessary to load manage[1] or re-negotiate to avoid penalties). Base load will be the mean of the three lowest months, electrical heating is the seasonal, temperature related load, i.e. the excess over the base load.

Correlate total energy input against temperature to find the base temperature for the site.

Use the base temperature, internal temperature, annual mean external temperature, and energy input to estimate the sundry gains. If the base temperature is that at which the SG is sufficient to maintain internal temperature the ratio of Sundry Gains to Heating input will be the ratio of internal - base temperature to base - mean external temperature.

$$SG = \text{Heat In} \times (T_{int} - T_{base})/(T_{base} - T_{ext})$$

Use the degree of scatter to estimate the wastage due to poor controls. Because the regression line represents acceptable internal temperature, anything above the regression line is wastage due to poor control. Taking this a step, further one could say

[1] modify or time activities on site to reduce peak demands, so as not to incur maximum demand penalties.

that since all points on the graph represent acceptable internal temperature a line parallel to the regression line could be drawn through the point of best energy/temperature, giving a new lower base temperature, and anything above this line is wastage. This was first attempted using a spacing of one standard deviation of the points from the regression line, to allow for errors in temperature and energy measurements, but the base temperatures predicted were so low that unrealistic results were generated. It was then attempted using a lower line at a 95 percentile probability of being acceptable below the original regression line[1]. Results from this were acceptable, but it was decided that for safety it was better to stick with the original regression line to find base temperatures.

7.5.3.6 Overheating

From the energy signature, one can find the heat input per degree centigrade. Compare the internal temperature against recommended values, and calculate any saving possible from reducing the temperature.

7.5.3.7 Sundry Gains

There will be two main components to sundry gains, electrical and metabolic. Metabolic gains can be estimated from man hours worked. The part of the electrical input contributing to sundry gain is then the total SG minus the metabolic gain. The rest of the electrical input may be being used to circulate air, work material, etc., i.e. doing work which doesn't contribute to heating the building. In a manufacturing site the metabolic SG may be relatively small, while an office will have both a significant

[1] Consider the line as the peak of a bell shaped prism, a normal distribution curve lofted into 3D along the regression line.

metabolic SG and a significant proportion of its electrical input contributing to SG (by lighting, office machines, etc.) For the purposes of this work the following has been adopted:

Metabolic SG = [(Office Staff x 180) + (Manual Staff x 270)] x Annual Hours / 1,000

7.5.4 Quantification Of Heat Losses From The Building

7.5.4.1 Fabric Loss

Fabric, or conductive, loss can be calculated from the U value, building envelope area, internal temperature, and mean external temperature.

$$\text{Fabric Loss kWh} = \text{U value} \times \text{Area} \times (T_{\text{internal}} - T_{\text{external}}) \times \text{Annual Hours} / 1000$$

7.5.4.2 Direct Reject

Direct reject of energy will be by such means as forced ventilation and water drainage. Ventilation air could be taken into account in the infiltration losses. One component can be found by assuming that all electrical energy not accounted for by electrical heating or sundry gains is going to be direct reject via fans, stored energy in products, etc.

All DHW or process energy supplied is either dissipated inside the building or else goes out as direct reject to the drain. Direct reject of heat from DHW and process cooling can be evaluated if the total water flow (mixing irrelevant), supply temperature, and external drain temperature are known.

$$(T_{drain} - T_{supply}{}^{1})\, C_w \times \text{mass flow} = \text{water direct reject}$$

In the absence of any losses not accounted for elsewhere, electrical direct reject, e.g. from ventilation systems, will be the excess of the total electrical and metabolic gains over the sundry gains previously calculated.

7.5.4.3 Infiltration Loss

For energy inputs and outputs to balance, Infiltration Loss must equal the difference between the sum of the Heating and Sundry Gains minus the sum of Fabric loss and Direct Reject.

Infiltration Loss = (Heating + Sundry Gains) - (Fabric Loss + Direct Reject)

This is in kWh, but it is useful to convert to Air Changes per Hour for comparison against standards.

Assuming that the gaps around doors and windows are unlikely to exceed 1% of their area, the resulting maximum ACH due to draughts can be calculated from the volume flow through the gaps divided by the building volume. Typical winter wind speed in Britain is 5 m/s.

$$\text{Draughts ACH} = \frac{5 \times 3600 \times 0.5 \times 0.01 \times (\text{Door Area} + \text{Window Area})}{\text{Building volume}}$$

Any excess of infiltration loss above this is likely to be due to doors and windows left open or forced ventilation. The recommended ACH for the site can be found from standards, and wastage due to doors and windows left open and poor draught-proofing

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[1] T_{supply} typically 15°C

can be quantified. For example, if the energy signature indicates 6.3 ACH, and the likely draughts due to gaps is 4.5 ACH, then 1.8 ACH is wastage due to open windows. If the recommended ventilation for the site is 2 ACH, then 2.5 ACH is wastage due to poor draught-proofing.

7.5.5 Energy Use Breakdown

Construct graphical breakdowns of energy use based upon kWh and cost. Do the same for building losses.

7.6 Quantification Of Possible Financial Savings

7.6.1 Recommendations Based Upon Compound Savings

Identify key measures which will have a knock on effect on other measures. These will be things such as reducing the room temperature and turning off unused lights, which reduce the heating and electrical loads, making insulation or lamp replacement take longer to pay back.

Rank the key measures first, and the other remedial options by SPBP. Take the shortest simple pay back period option first, if two options have same SPBP take the cheapest first. Calculate new potential savings for the next option due to the effect of the remedial measure taken. Predict when the energy saving action has saved the equivalent of the cost of the next option. Plan to undertake the next option at that time.

Repeat the procedure as options work through, and prepare a five year investment plan based upon above method.

7.6.2 Calculation Of The Effect Of Individual Low Cost Measures

7.6.2.1 Quantify Financial Costs

From the tariffs and consumption data calculate an average heating cost per kWh, similarly calculate an average electrical cost per kWh.

Use these to calculate the financial cost for each of the areas of wastage considered. Estimates of costs from fabric losses, infiltration, overheating, DHW, controls, etc. will be based upon the average heating cost, while lighting, compressed air and any other electrical inefficiency costs will be based upon the average electrical cost.

Estimate the costs of individual remedial measures. Adjust costs to take into account of the fact that electrical savings will reduce sundry gains, incurring an increase in heating to compensate. Calculate the simple pay back period for each option.

8. THE ENERGY MANAGEMENT PROGRAMME

The energy management programme breaks down into modules which realistically represent the stages a human would have to work through when analysing energy use on client sites. These tasks can be summarised as follows:

1. Acquiring a new client and deciding whether a useful saving is likely to be possible on the site. Then generating a preliminary assessment for the site which indicates whether or not further work is worth doing.

2. Surveying the site and recording relevant information about the building's construction, energy systems, condition, use, working patterns, etc.

3. Logging monthly energy consumption levels and tariffs for a representative year, and identifying the meteorological data needed for that site and year.

4. Correlating energy usage against meteorological data to giver the building's energy signature, and inferring the major components of the energy balance.

5. Quantifying the potential for low cost energy saving measures and suggesting a plan of investment.

To support these tasks there are databases of meteorological sites and data, constructional details, etc., which can be edited and developed by the user via menu driven forms.

8.1.1 Data Input

It was originally thought that a file of client site data would be created from the survey. This and files of meteorological, structural, tariff, etc., data would then be related to a file of remediation measures by an inference engine to carry out the energy management routines, and the results fed to an output file. This was to have been a DOS based package written in Borland Turbo C, with the data stored in ASCII files[1]. It was originally intended to use paper based questionnaires for gathering data on site energy use, and then create a single data structure from them on which to run the programme. The early C++ / DOS version of the programme started doing this, but had the data input screens identical to the questionnaire forms so that data could have been directly input to the structure on a laptop PC by the user while doing the site survey. It was later decided that the drop in price and resulting increase in availability of laptop PC's made the paper based data gathering process obsolete, though it may be useful to include as an option.

There were problems with data integrity when using simple binary and ASCII files to store the data structure, and so it was decided to switch to using the Paradox type database format which could be accessed by C++ / DOS programmes via Borland's Paradox Engine utility.

About halfway through the development Borland released Delphi, which offered the possibility of compact, fast Windows based programmes with good database features, so it was decided to change from Turbo C to Delphi as the development language.

Using a standard database file format offered a number of advantages in terms of data security and integrity, for example, not only can you reliably store and retrieve an item of data, but you can ensure that it is the correct data type on entry. There is also the

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[1] consideration was given to the development of the system using off the shelf spreadsheet, database, and word processor packages linked to each other, but such a system would not have been stand alone or as completely

advantage that the data stored could be accessed by other standard office applications such as databases and spreadsheets. In this way the energy related data could be shared with other applications dealing with different aspects of the organisations management. For example, the energy billing data could be shared with other accounts data by a spreadsheet application to give an overview of site costs. With the switch to a Delphi / Windows programme this made even more sense, because the database engine provided with Delphi accepts any format which meets Microsoft's Open Database Connectivity specification, and ODBC allows such data to be accessed by most contemporary applications, as well as across networks such as LAN's and the Internet.

One necessary change which soon became apparent was the need to have multiple data tables rather than one large structure. The number of data fields for even a relatively simple energy survey runs into many hundreds. This slows down the programme because of the time taken to find a particular field in the file, and means that each time a field is changed the whole file has to be modified. Another disadvantage is that future development is restricted by the data structure, which would not be easy to modify during use.

Avoiding these obstacles was achieved by having a relational database for site records, where tables relating to various subsidiary aspects of the site structure, energy use, etc., are linked by key fields, such as 'Company', 'Site', and 'Year', set down in a site

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versatile as a custom designed product.

administration record[1]. The key fields identify the appropriate records in all of the relevant database tables.

Another advantage of using multiple tables in a relational database is that at some point in the future the database can be expanded to include further tables relevant to other environmental management functions such as water, hazardous chemicals, or waste management. New computer based tools for manipulating the information held in the database can also be developed in a modular fashion. In this way the basic energy management package can form the seed for a continuously expandable energy and environmental management system, or even a general management system, simply by developing new tools and tables to use with it.

8.1.2 Output

It was originally envisaged that the results from the energy management routines would be stored in an output file, which would be accessed by the human energy manager to write the report in some standard word processing package[2]. As the programme developed it made more sense to create a draft report which could be reviewed and edited by the human energy manager. Unfortunately the Report Smith utility supplied with Delphi is big, slow, and clumsy. Other approaches to the reporting functionality may therefore be appropriate in future developments of the programme.

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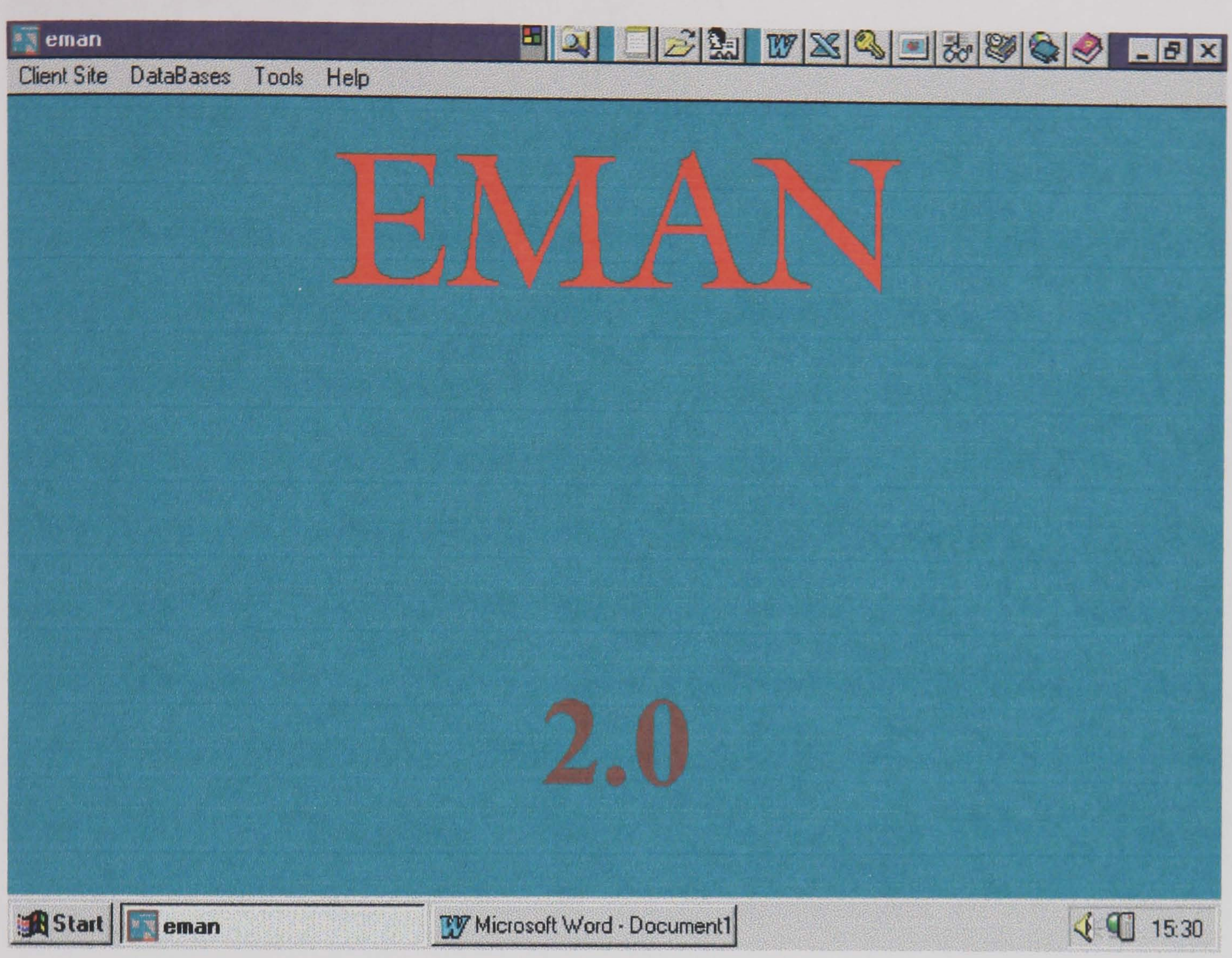
[1] Using a record or case number would be better, but it is easier to identify sites by name, etc., during development.

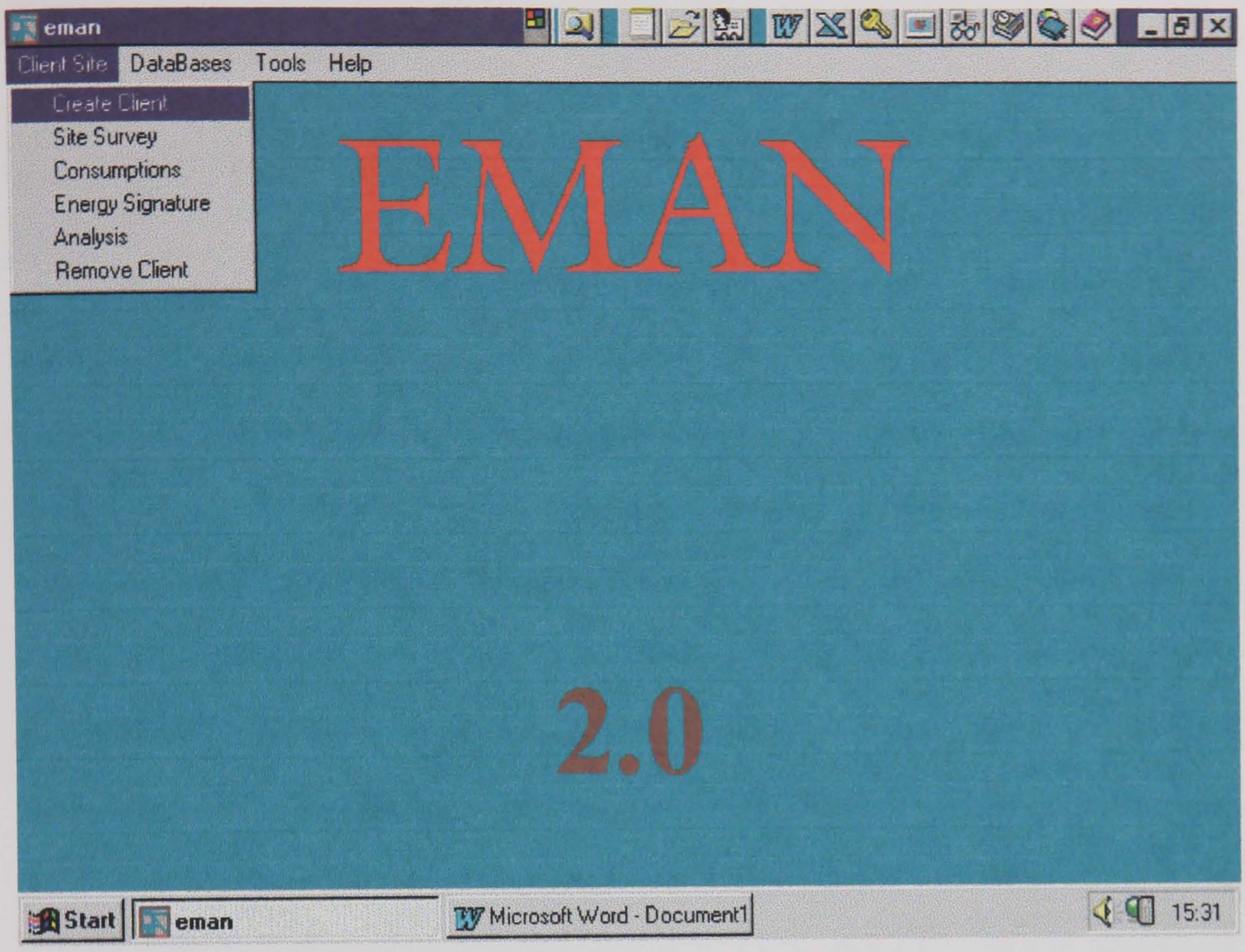
[2] Rather than trying to develop a stand alone text editor, with associated device drivers, etc.

8.2 The Main Screen



The Main Screen

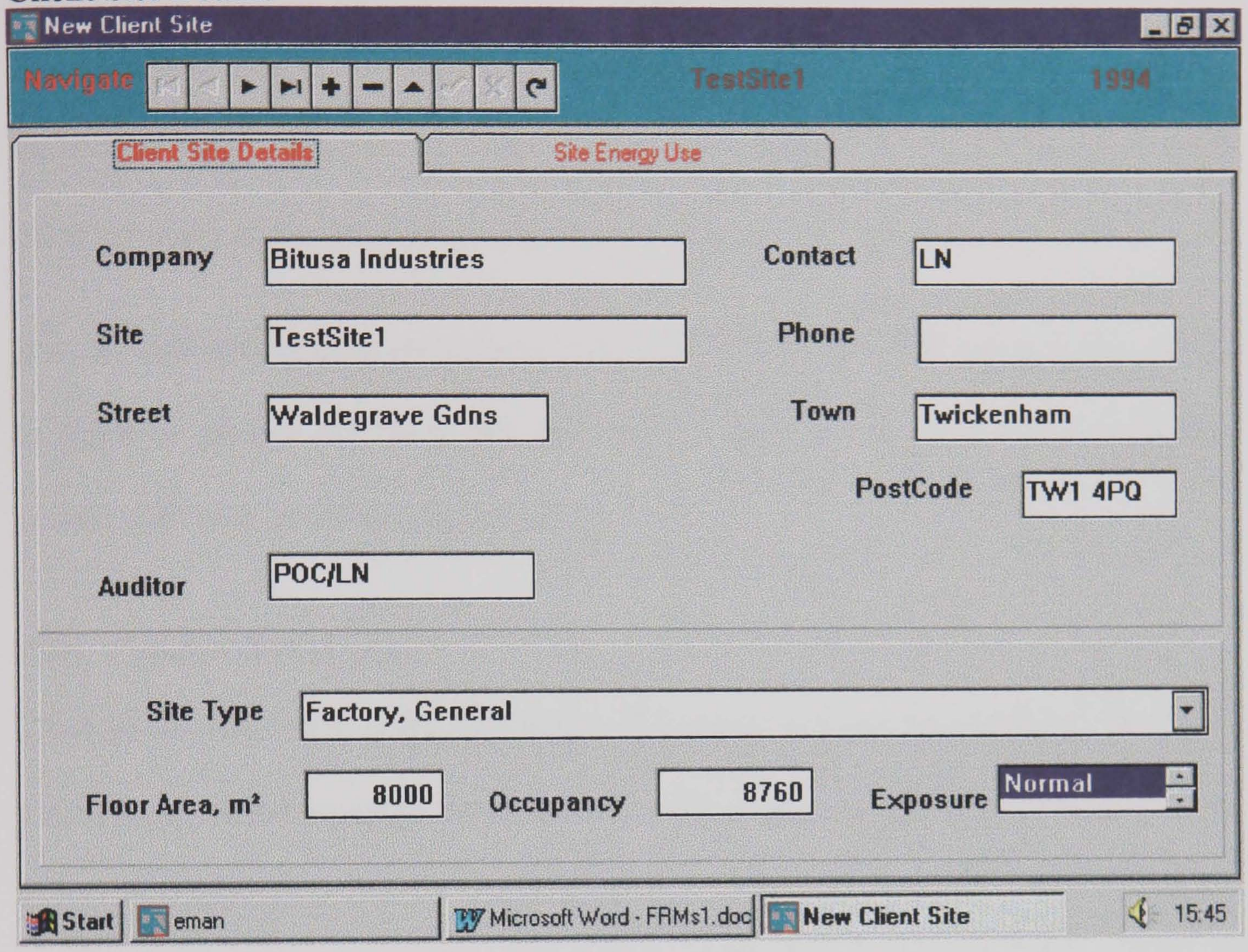
The Main Screen is the opening screen of the programme. It allows the user to call up the other programme modules via pull down menus on a title bar. As well as providing access to input client site related data, menus allow access to Databases of meteorological, constructional, etc., information, which the programme uses, and tools for Boiler Logging and Efficiency calculations, which are additional to the energy management system programme but may be of interest to certain users.



The Main Screen showing operation of drop down Menus

8.3 Creating a Client

Client Site Details



Client Site Details

The first management task is to create a client site record for the case in question. This gives a unique record for that Company, Site Name, and Year, and acts as a master record to which all other databases tables will be related. It would be more elegant to simply have a unique case number relating different tables, but during development it has proved less confusing to use the Company, Site Name, and Year as key fields which occur in all client site related tables (making it easier to see that you are not mixing the data from different client sites into one record). For a commercial version with hundreds or thousands of case records it might be appropriate to modify this approach however the small amount of memory taken up by duplication in a few tens of records does not justify the reworking of the programme at this time.

At this point a record is also made of other information relevant to the administration of the case, such as the person to contact at the client site, address, telephone number, etc., and who the responsible auditor is from the energy management team. If, for example, the auditor fell under a bus, all of his cases could be flagged up by an SQL query so that other members of the team could take care of them.

It would probably also be possible to add a <LIVE/DEAD> checkbox to make it easier to delete or archive old cases, but that decision will be left for anyone developing a commercial version of the programme.

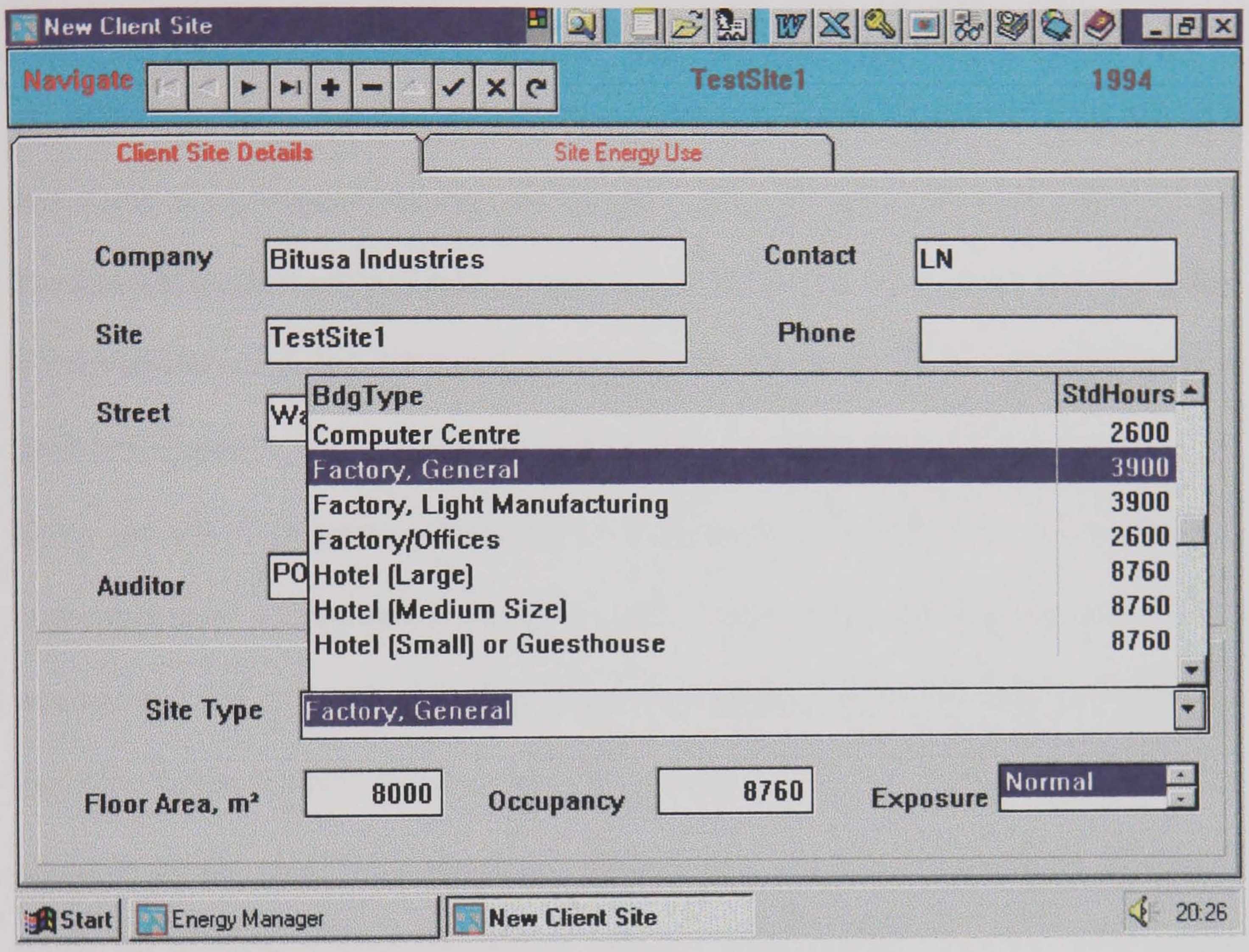
8.3.1 Create Client Form

The creation of a client is the first step in the energy management system. The Create Client form creates a unique client record to which all other data can be related as the energy management of the site is investigated.

A key step in this procedure is the calculation of performance indicators for the client sites, and inference from them of the likely financial savings possible. Only if the financial savings justify it will further work be done on identifying energy inefficiency.

The Create Client form comprises two parts, administrative data and data necessary for calculating the building's Normalised performance indicator.

Administrative data includes :- Company, Site Name, Street, Town, Post Code, who the contact on site is, their telephone number, and who is dealing with the client. NPI related data includes :- Type of Site (e.g. Primary School, Offices, etc.), Floor Area, Occupancy, Exposure Factor, Annual Energy Bill, Billing Year, Degree Days for that year, Primary and Secondary Heating Fuels and Annual Consumptions, Domestic Hot Water, and Non Heating Electrical Consumption.



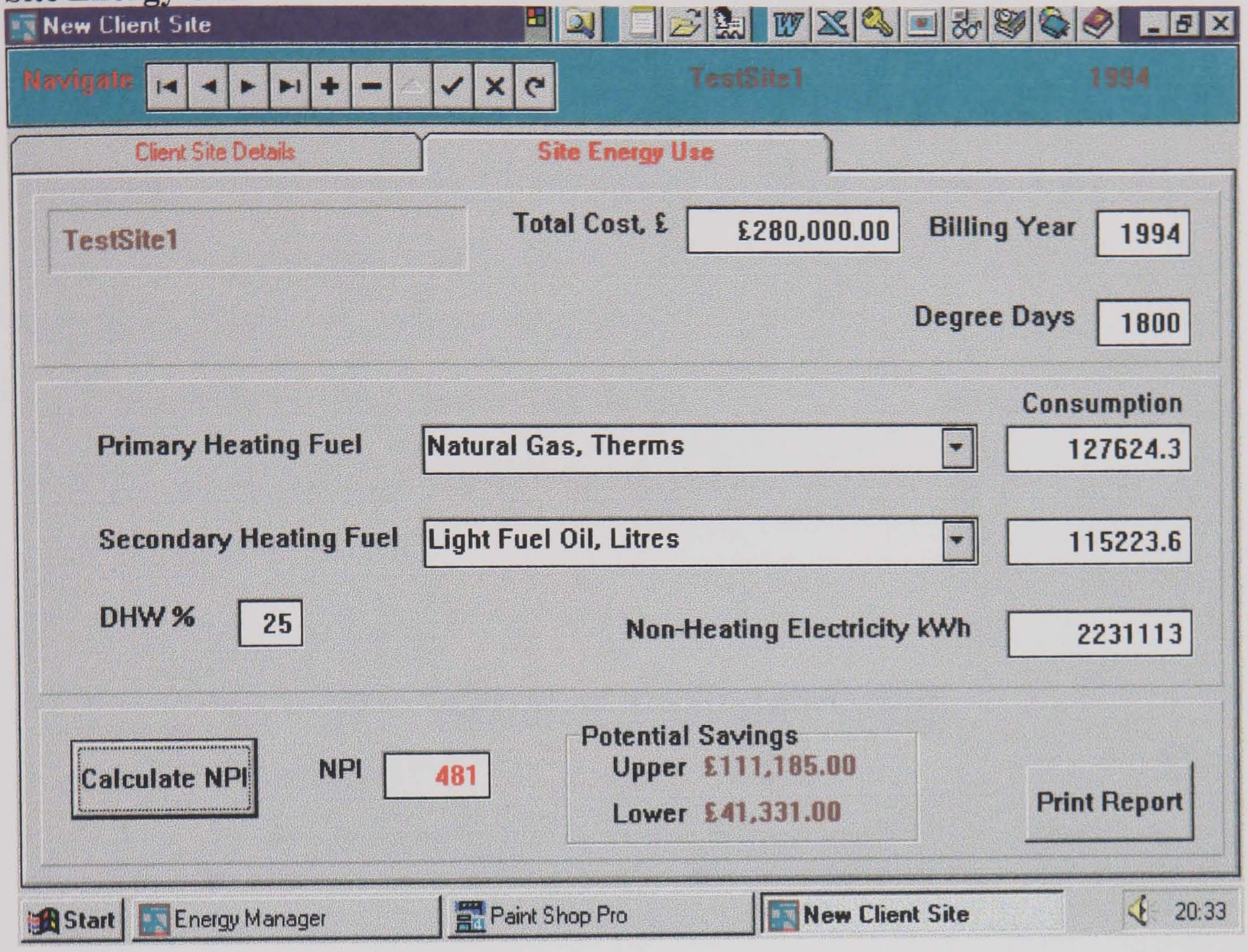
Client Site Type can be pulled down from an expandable database

Information such as Type of Site and Fuel Type, which generally fall into a small set of known options can be chosen from drop down lists, rather than having to be written in every time. These drop down lists draw on databases of standard types of fuel, type of site, etc., which are part of the package. Thus fuels, constructional, etc., databases can be edited and enlarged in a separate area of the application to allow for continuous revision and upgrading. In this way less common options can be added to the database as their details become known, allowing it to be adapted to deal with non-standard sites.

There are only three exposure levels used for the NPI calculation and the relevant level can be chosen from a scroll box.

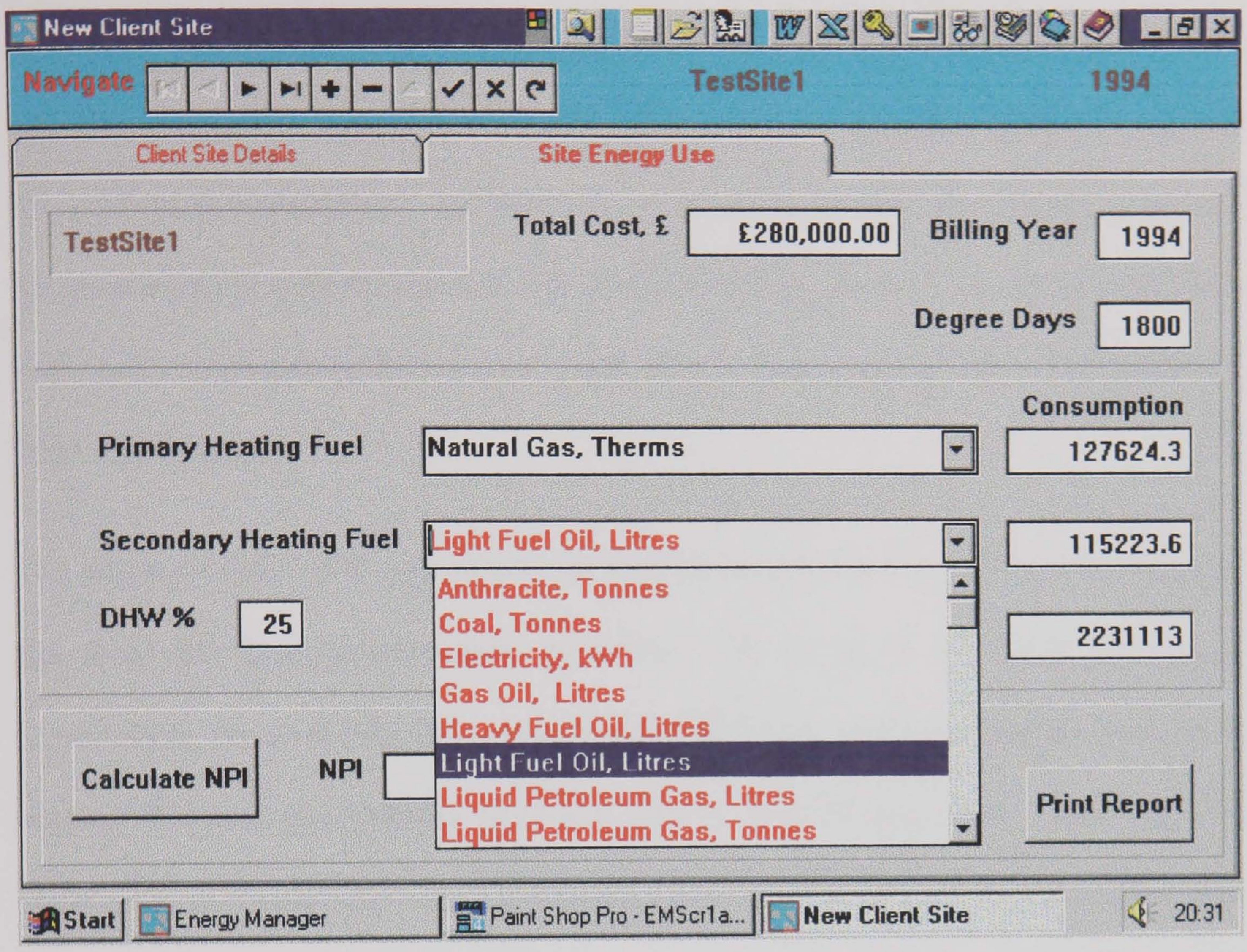
The Company, Site, and Billing Year are used as key fields for identifying the client, and also for relating the new record being created in the Admin database table for the new client to any records that may be set up at a future stage in other data base tables. The EMAN application has been designed to only create records in the available tables if information is entered. This reduces the space occupied and access time because the application doesn't create a record in all the data tables for each client site, only those tables for which relevant information is available. It is important to include this element because a large area of memory would otherwise be set aside whenever a client was created, but in many cases the energy management procedure may go no further than calculating the NPI and the client deciding that it wasn't worth continuing. If, as seems to be the case, most potential customers get no further than the initial enquiry stage, the computers hard disc would then be quickly filled up with client records containing empty fields.

Site Energy Use



Site Energy Use

At this point it is important to know if it's worth going any further. The key to this decision is to assess whether the potential for energy savings makes it worth spending time and money on improving the energy efficiency of the site. This assessment needs to be made from a small amount of easily processed information, so that it can be a cheap way of identifying worthwhile sites and eliminating sites which do not warrant further work.



Fuels can be pulled down from a database

The New Client module allows the site type, exposure factor, and fuel types to be chosen from pull-down menus. The annual degree days, occupancy, units of fuel and electricity, percentage of fuel used for domestic hot water, and total energy spend can then be entered and an NPI value calculated for the site.

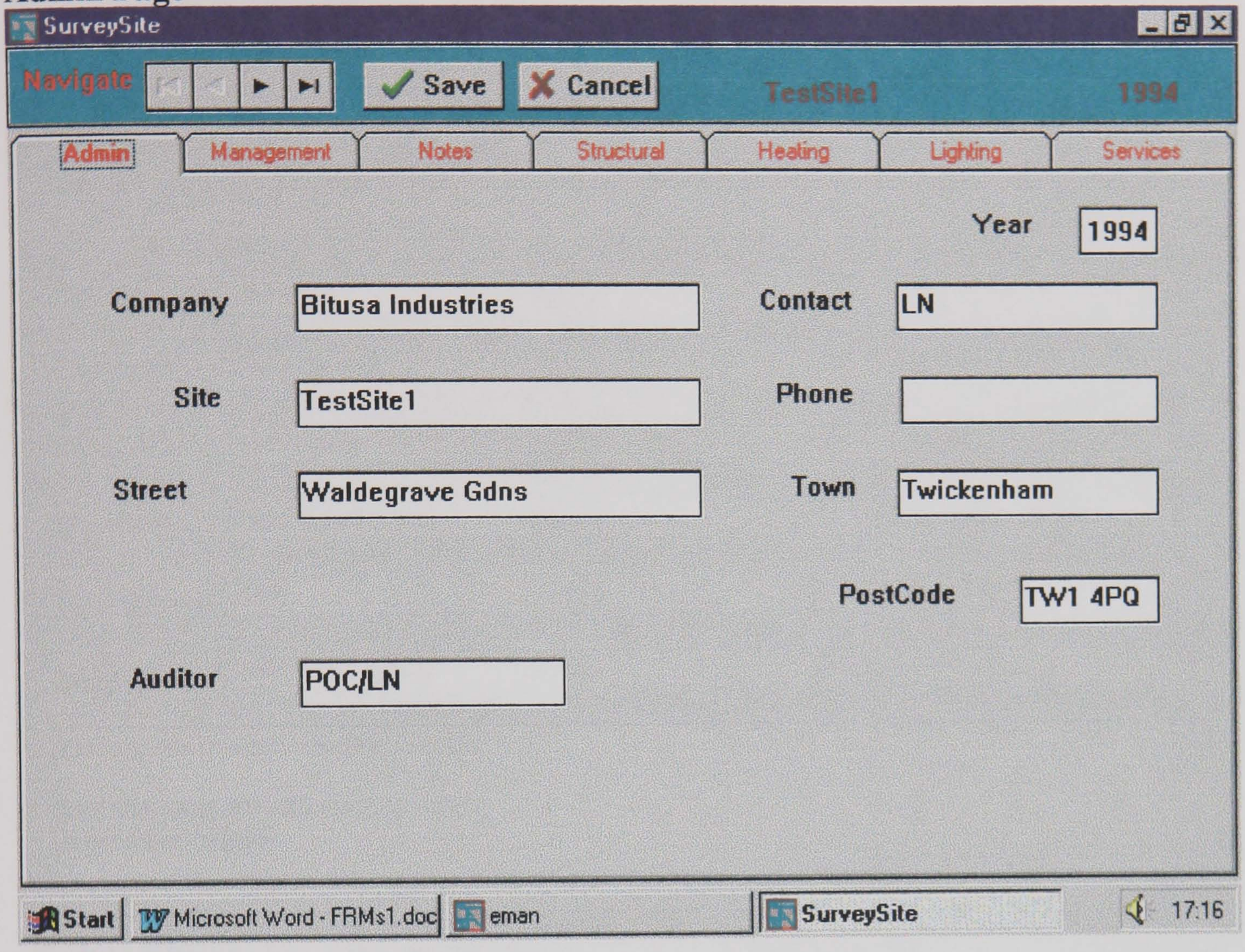
The client site's NPI value is automatically compared against BRE's figures for sites of that type, and upper and lower estimates of the proportion of the energy bill which could be saved at low or no cost are calculated. If the lower estimate for potential annual saving exceeds £500 the saving justifies the expense of a more detailed investigation, or if the upper estimate exceeds £1,000 it may be worth further investigation, otherwise the cost of further investigation is probably not be worthwhile, and the programme indicates this. These are arbitrary figures based upon experience of the rates charged by small environmental consultants, though they would not be valid for certain top management consultancies. It would be possible in a future version of the programme to store this kind of data in an INI file so that it was easily altered, but it is probably unnecessary because the auditor is free to make his own judgement on what's worthwhile.

The results of this initial assessment can then be printed out for the client, or saved to file from the ReportSmith report generator. By virtue of the Open Data Base Connectivity protocols the data and results stored can also be accessed from most modern PC based spreadsheets, databases, and word processors. This offers users the opportunity to develop their own interfaces to the energy management programme, or to integrate it with other programmes such as accounts packages. It would also be possible for someone managing distributed sites to develop simple interface programmes which access the energy management programme's databases over the Internet.

8.4 Site Survey

The Site Survey form is presented as a multi-page notebook, with separate pages for various aspects of the survey.

Admin Page

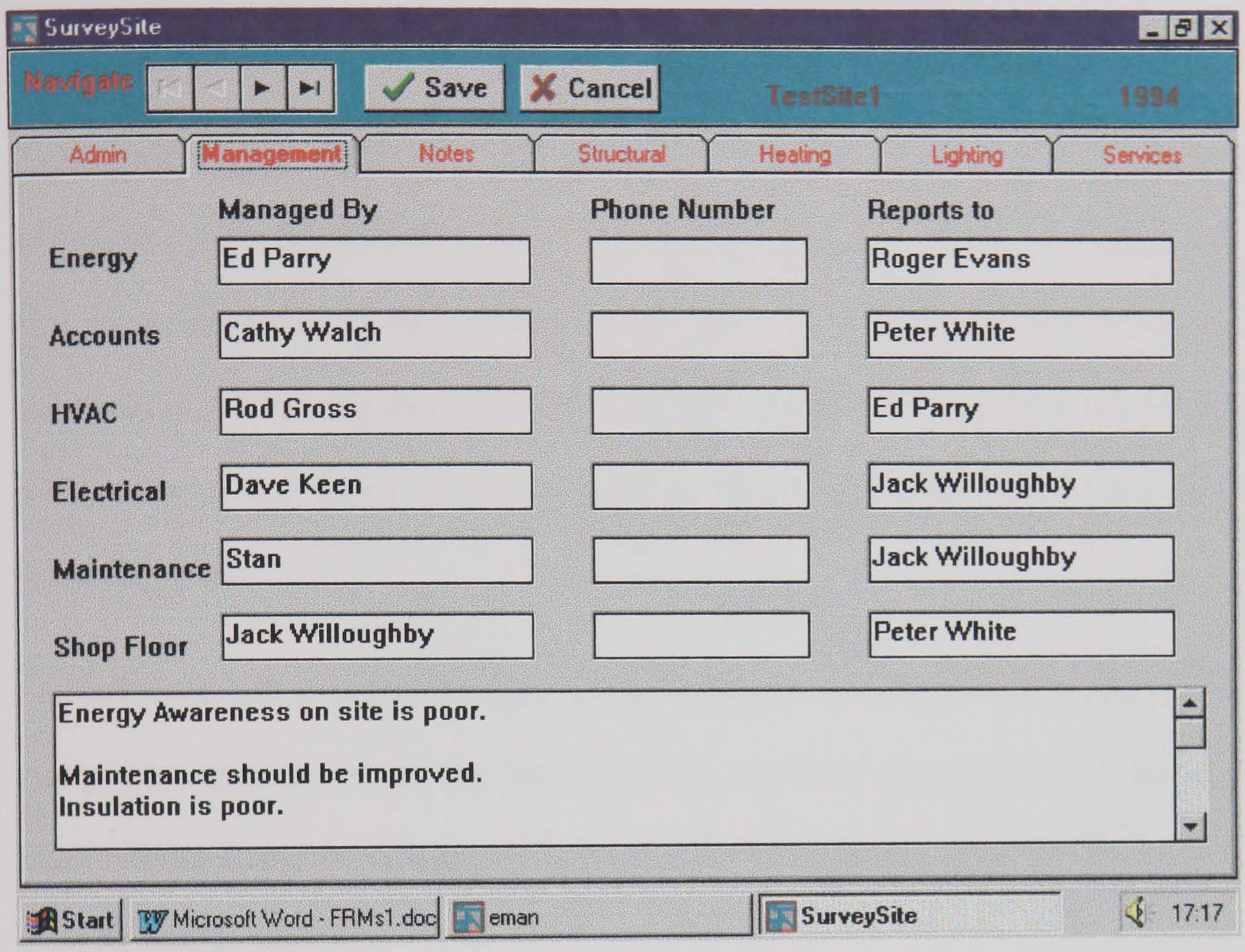


Admin Page

The Admin page is the first page in each client related module. It contains the identifying information and key fields from Admin Table records previously set up by Create Client, and simply allows the user to confirm that he or she is working with the correct client record. The teal coloured panel at the top of every screen related to client sites also indicates the site, as well as allowing the user to move between site records.

If, for example, there were a change of auditor, person responsible on site, or even company name, this data could be altered in the client records from the "Admin" page of whichever module was currently in use.

8.4.1 Management Page



Management Page

The Management Page briefly sets out who is responsible for various energy related functions, their telephone numbers, and who they should report energy related information to. This serves a number of purposes, from the point of view of the auditor it identifies who to approach for the necessary information when carrying out an energy survey or audit. If that person is unavailable someone else on that phone number may be able to help, or the person they report to could be contacted instead.

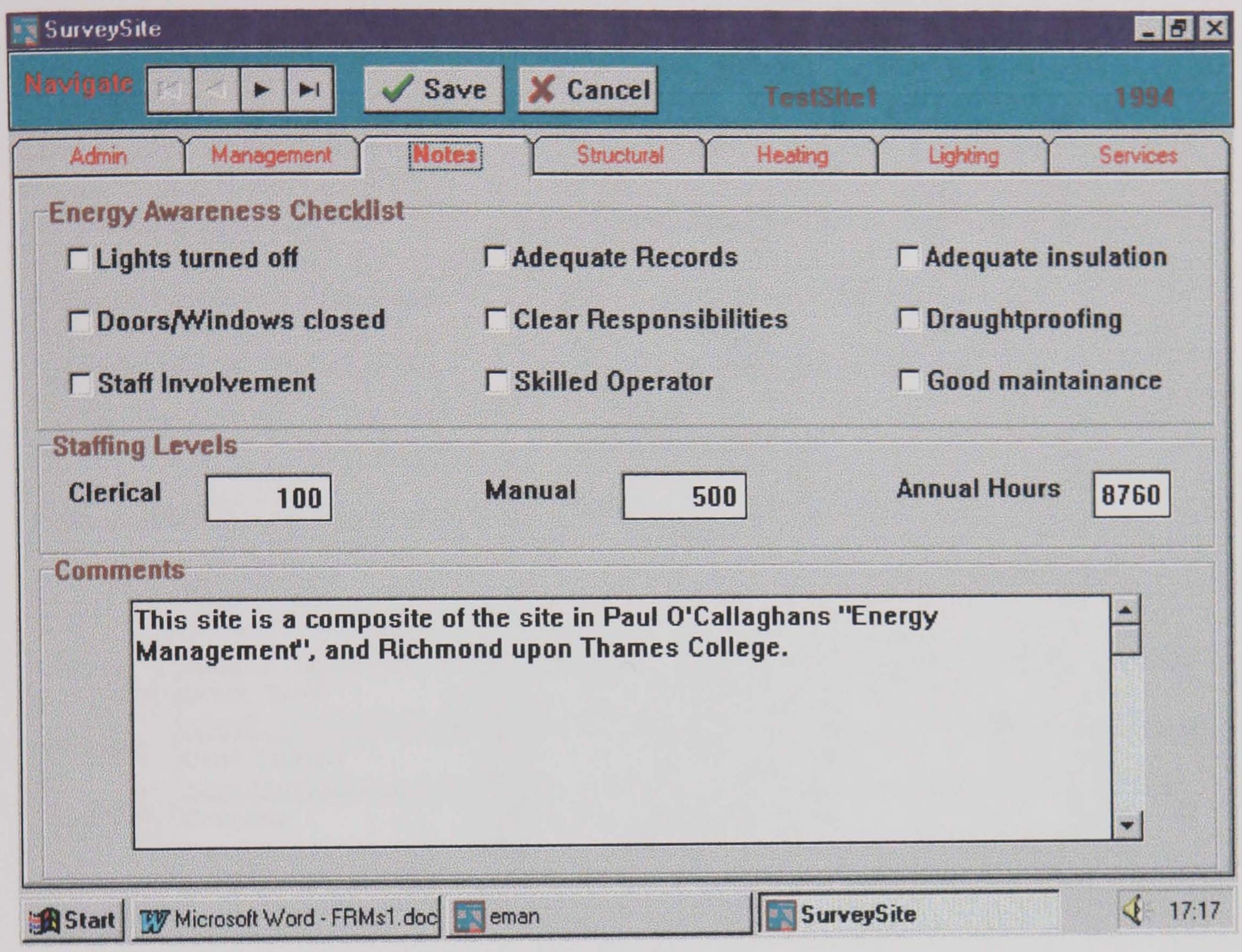
From the clients point of view it imposes some minimal form of energy management structure within the company's organisation. It identifies key energy related roles and forces the company to acknowledge them and make someone responsible for them. That person is then named as being the person to deal with that task, so there is no confusion about who's area of responsibility it is or who to approach to find out about that particular area.

It also places energy management within the area of responsibility of a senior manager or director. Even though that person may have nothing to do with energy management on a day to day basis, he may promote it because it's been made his baby, or at least make sure it gets done by the people down the line. It also gives those in energy related roles someone with authority and leverage to appeal to or pressurise if they want something done.

Lines of communication are clarified. Ideally everybody else should be reporting to the Energy Manager, but even if they don't do so directly he knows who they are and they know who he is, so everyone knows who to call on if anything unexpected comes up, or even for routine enquiries.

Instances where there is an energy related area without a named responsible person are automatically flagged by the programme, as are instances where that person does not communicate with the energy manager. These appear in the memo box at the bottom of the page. This memo also automatically comments on the answers given to the energy awareness checklist on the Notes page.

8.4.2 Notes

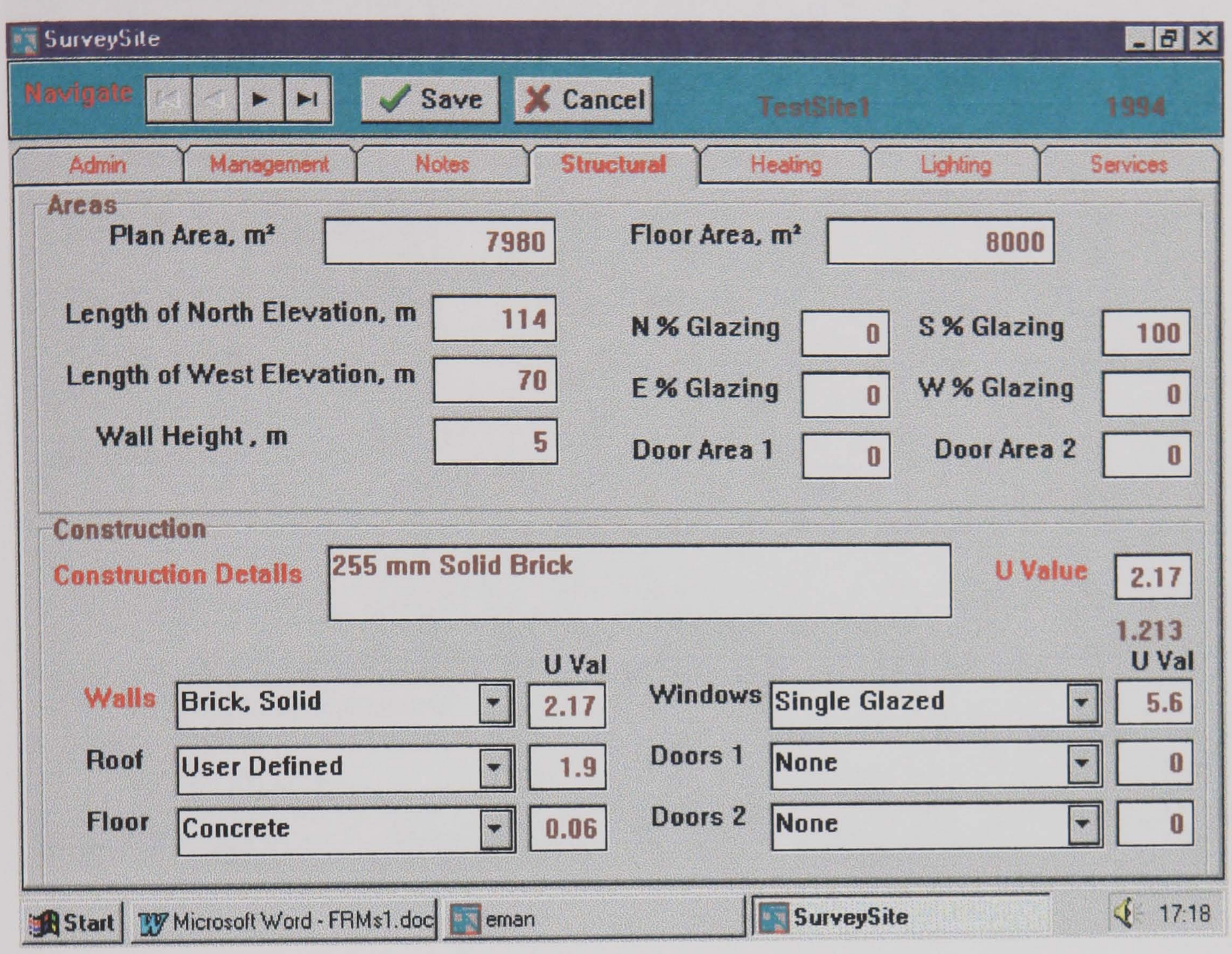


The Notes Page

The Notes Page allows entry of brief notes regarding impressions of the site. It contains an energy awareness checklist to give a picture of the level of ignorance or interest in energy efficiency on a site. As well as giving a rating for the awareness level, the checklist automatically generates memo items for the Management memo on the previous page.

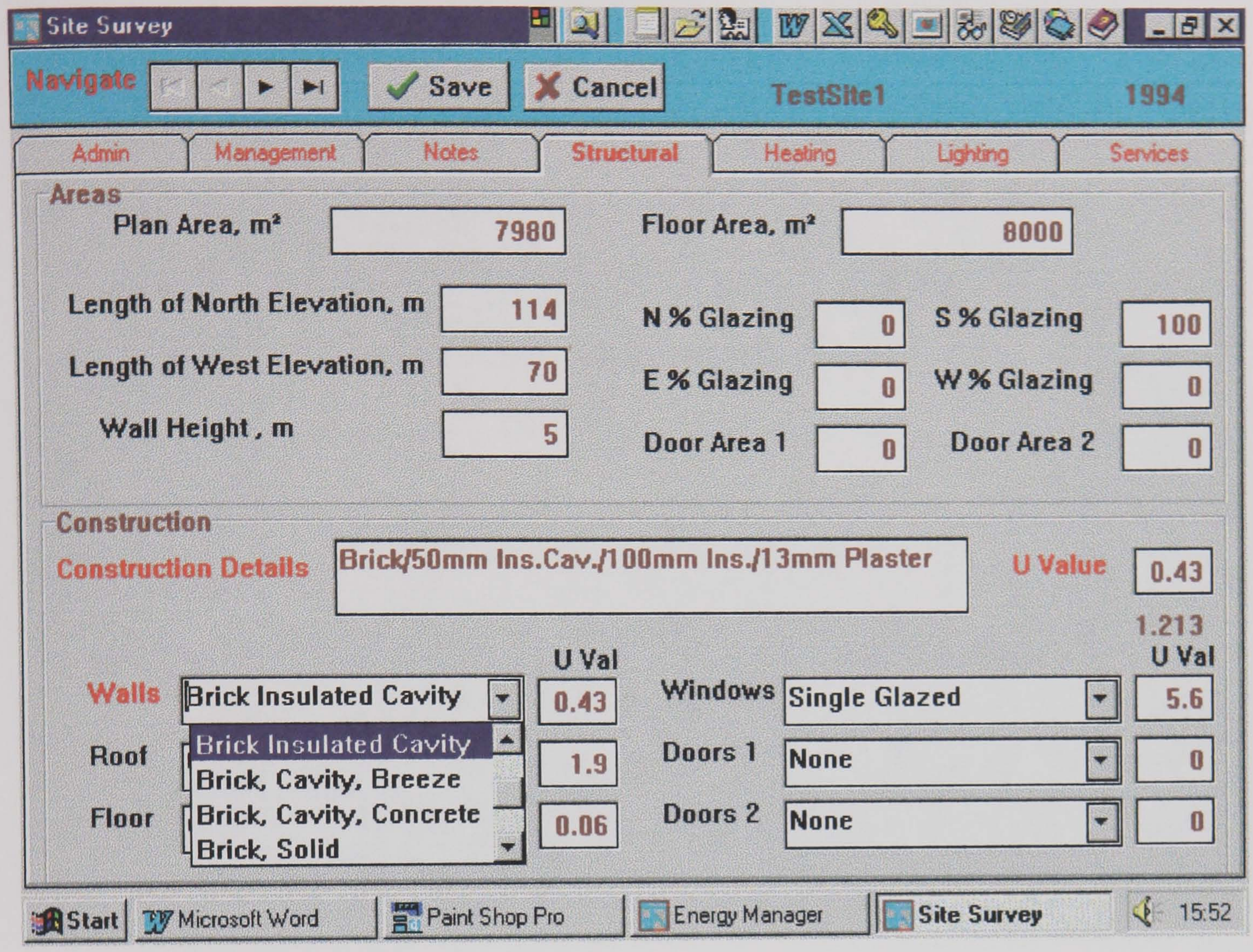
The staffing levels are recorded on this page, to generate a ballpark figure for the metabolic gains on site. At the bottom of the page is a memo box which the auditor can use to make notes while surveying the site.

8.4.3 Structural



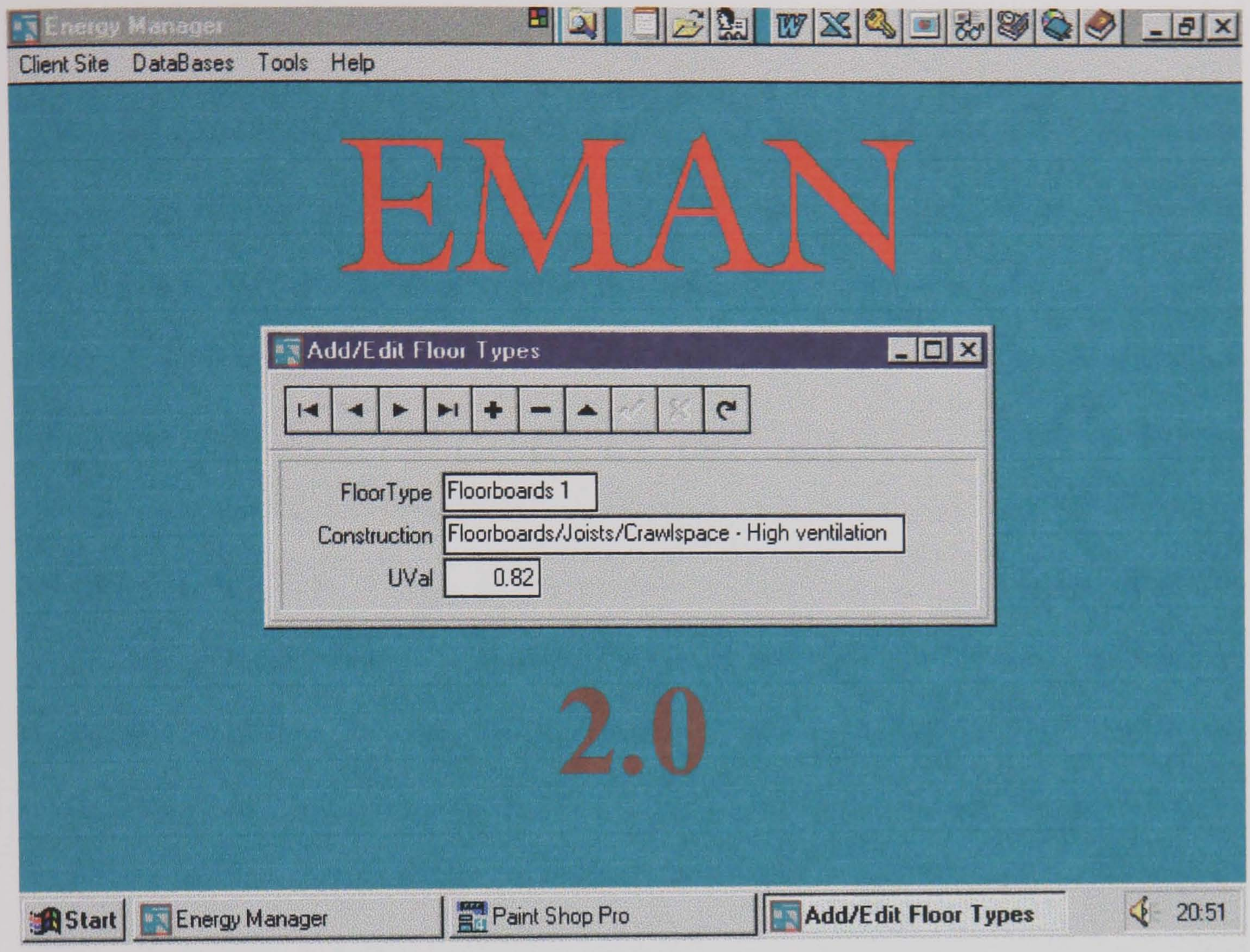
The Structural Page

The Structural page allows the building's dimensions and construction details to be entered, and calculates a U value for the site.



Wall Type and Details pulled down from the Database.

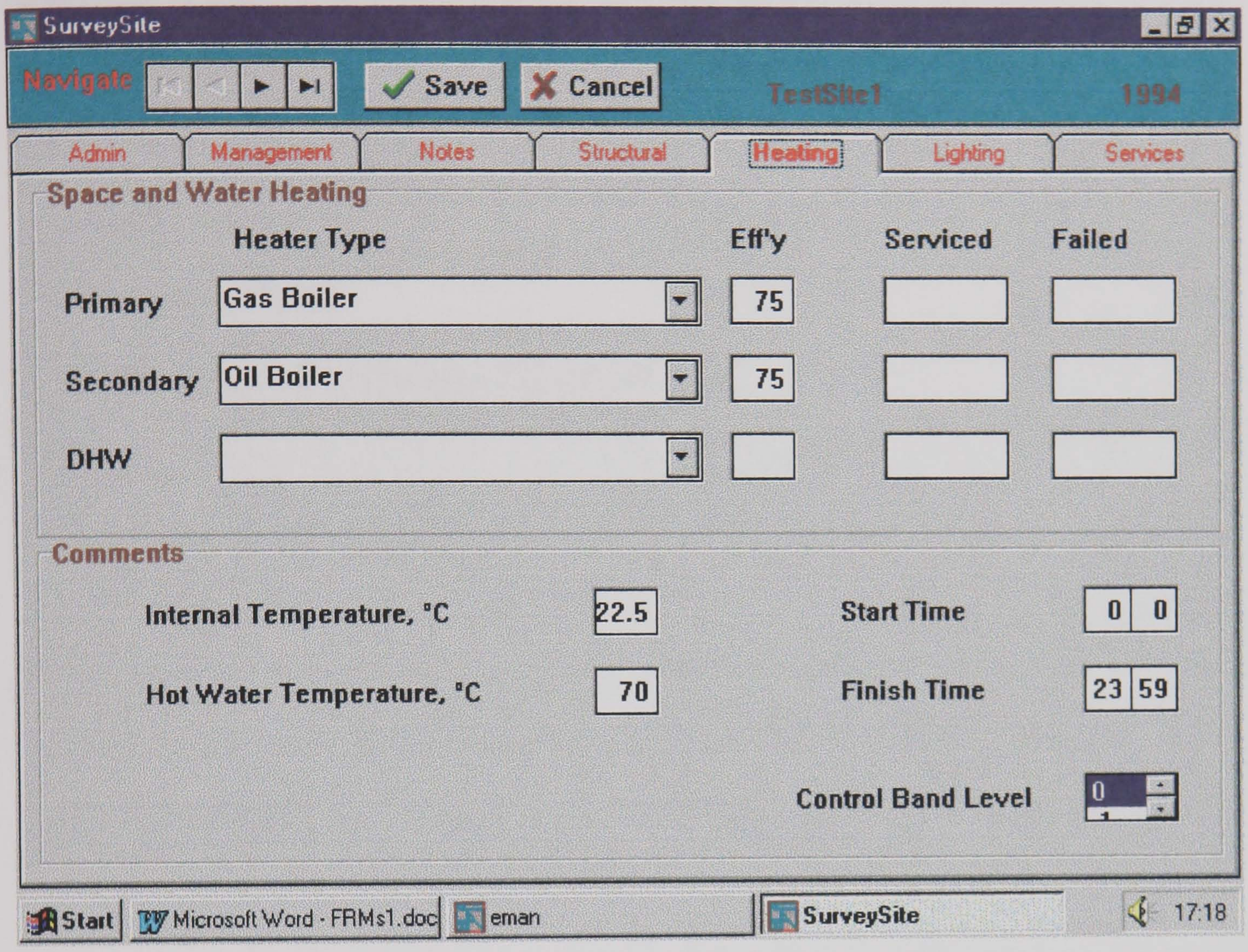
Construction types for walls, roofs, floors, window, and doors can be pulled down from construction databases, and the construction details and u value of the chosen component (title shows in red) are entered into the client site record.



The Floor Type Database Edit screen.

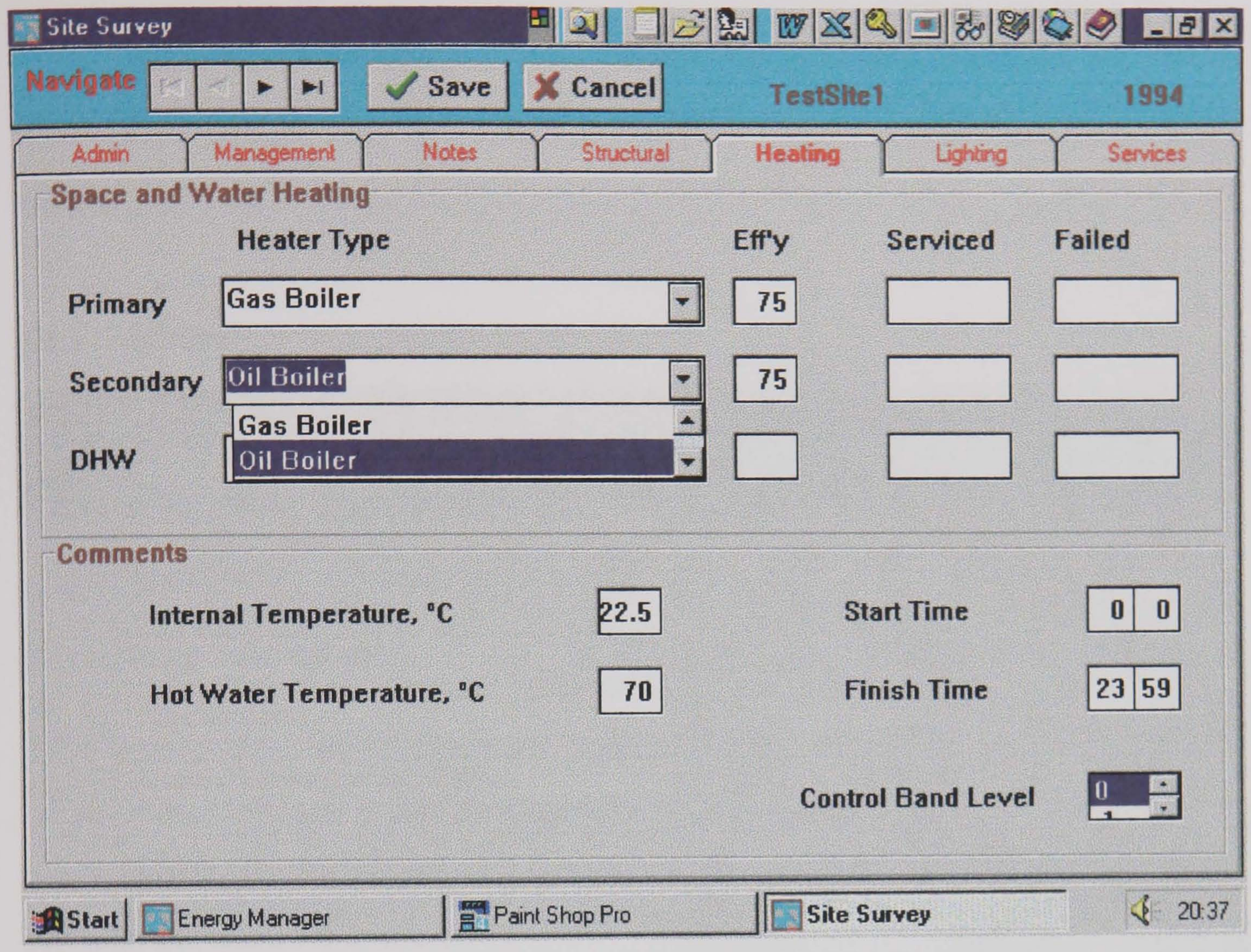
For unusual constructions the user can either indicate "User Defined" on the construction type menus and enter their own u value, or can update the construction databases with the new construction type (e.g., straw bale walls) so building up a library of different constructions which future users can pull down from the database.

8.4.4 Heating



The Heating page

The Heating page is for recording details of the client's space and water heating.

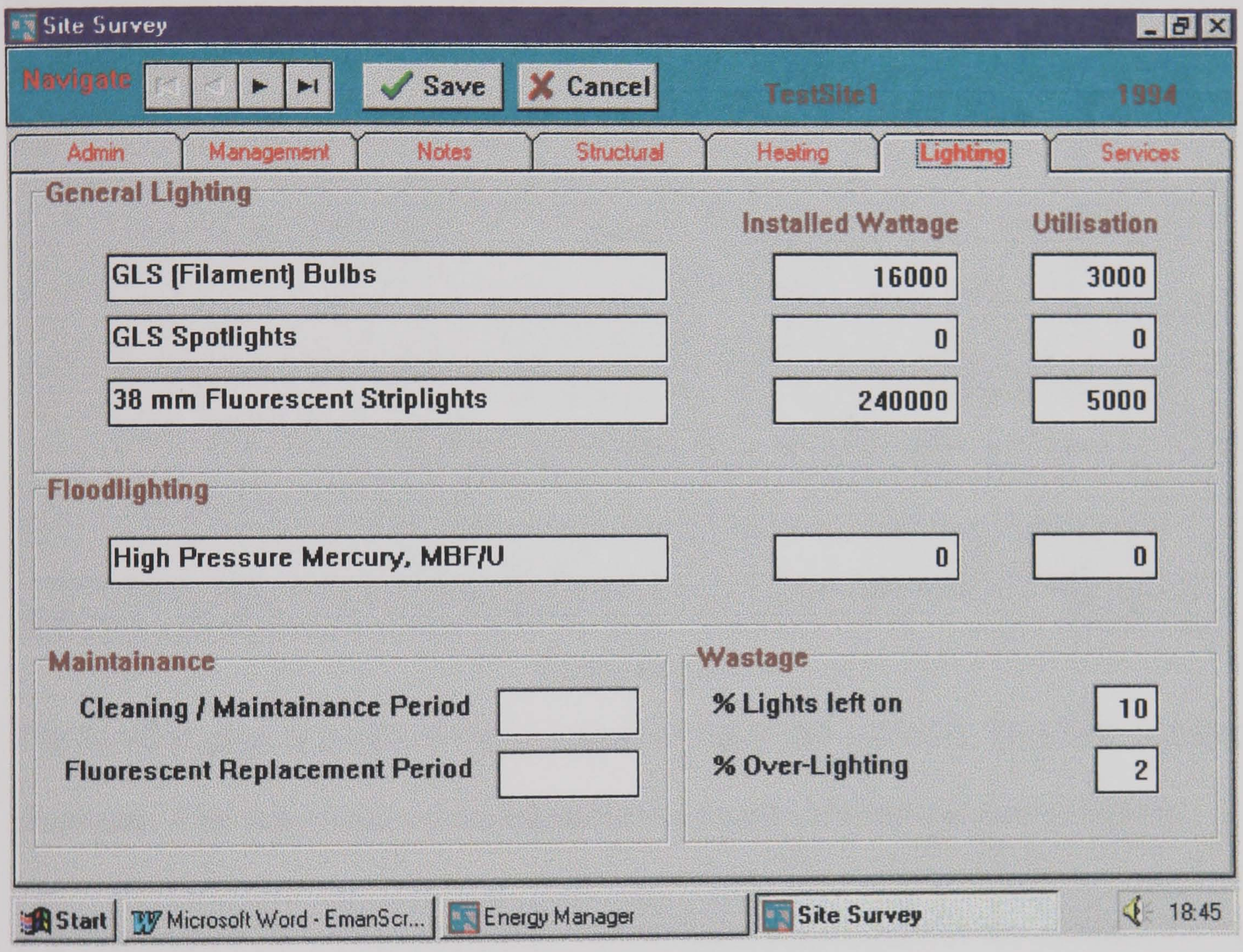


Primary, Secondary (e.g. back-up systems), and Hot Water Heater types can be pulled down from a database menu, which automatically offers ballpark efficiencies as a default. If there has been any accurate measurement of the client's boiler efficiency this can be entered instead. To try and force the client to keep records there are boxes for recording the dates when the boilers were most recently serviced and last broke down. These dates are not used by the programme, but by asking for them it should make someone remember that they have a log for the boiler house somewhere and start using it.

The operating temperatures and On/Off times are also recorded on this page.

The "control band level" as defined in current Building Regulations is noted, allowing estimates to be made at a later stage for the investment cost of improving the control system.

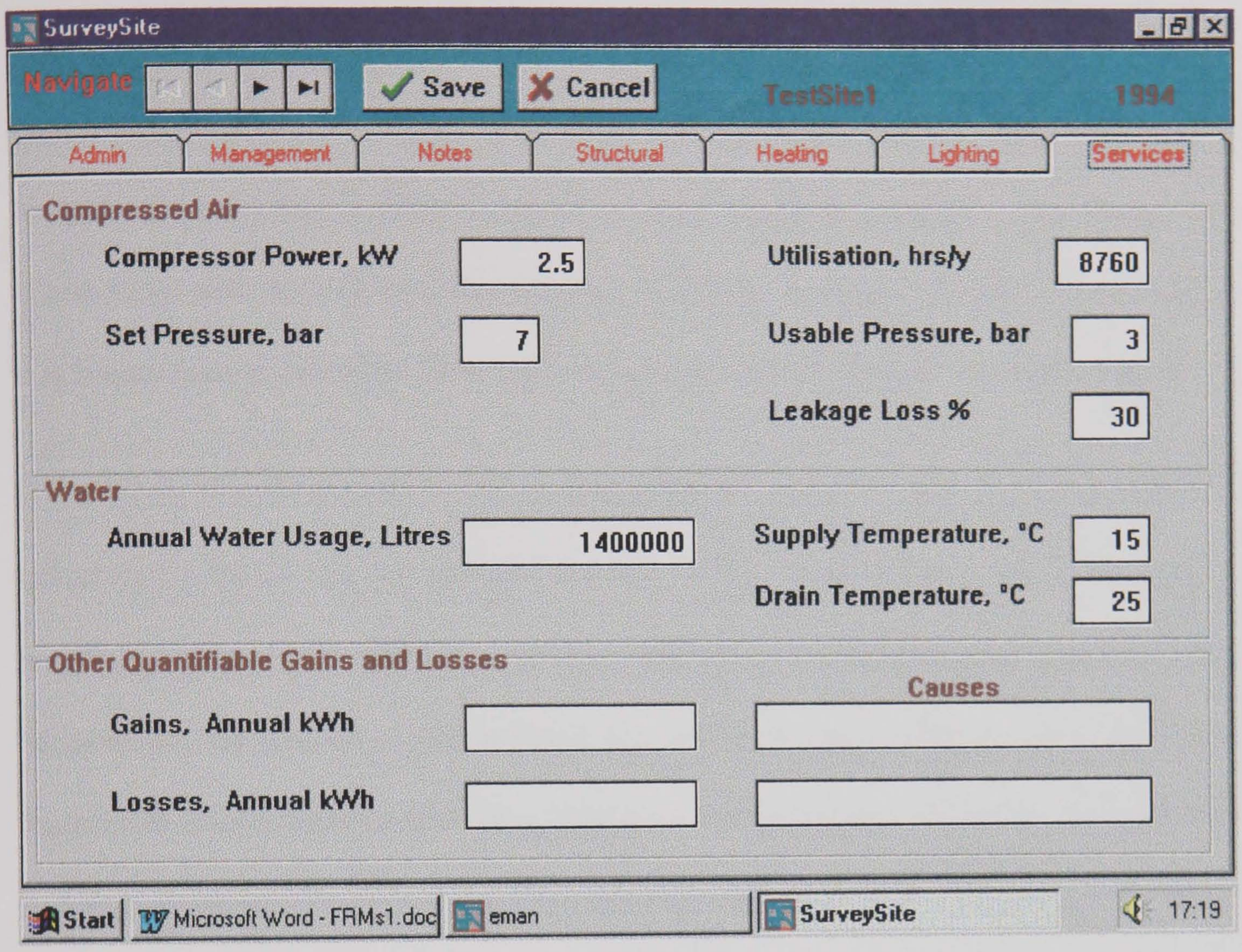
8.4.5 Lighting



The Lighting page

The Lighting page allows the installed load and annual hours usage of standard lighting types to be recorded. This information is used by the programme to calculate the potential savings from more efficient replacement lighting types. Estimates of the number of lights left on unnecessarily and of excess lighting levels are also recorded here, as are maintenance and replacement periods.

8.4.6 Services



The Services page

The Services page is provided for recording energy related services other than fuel and electricity. The two which are most likely to be found are water and compressed air.

The compressed air information allows an estimate to be made for the wastage due to leakage and over-pressure. The water usage, supply and drain temperatures, allow an estimate to be made for the direct reject energy waste water is taking down the drain. Some sites may have unusual processes taking place, so provision has been made for the user to note any identifiable gains and losses from them which can be later included in the site's energy balance (e.g. significant energy may be leaving the site contained in a manufactured product, such as chemicals or magnets).

It was decided not to have a Plant page, it would be too limited in scope because of the impossibility of prescribing generalised solutions which can deal with the immense variety of industrial plant and processes. Similarly for electrical plant it is only possible to apply general rules to Motors, and even they would best be dealt with separately. When faced with an indeterminate number of motors of varied type and characteristics it is impractical to deal with them within a general energy management programme.

It is unlikely that the motors would be changed even if they are shown to be inefficient, unless they were due for replacement anyway. If they were to be replaced the company would probably be carrying out a detailed analysis of what to replace them with, and because of the capital cost involved are likely to buy smaller, more efficient, replacements unless they require the flexibility offered by over-sizing for change of use or future development on the site. This is an area where an outsider cannot come along and make recommendations without really spending a lot of time working with the client to identify their needs and the best options to meet them.

Even Power Factor correction should not be applied to the site as a whole, but to individual motors and inductors, because

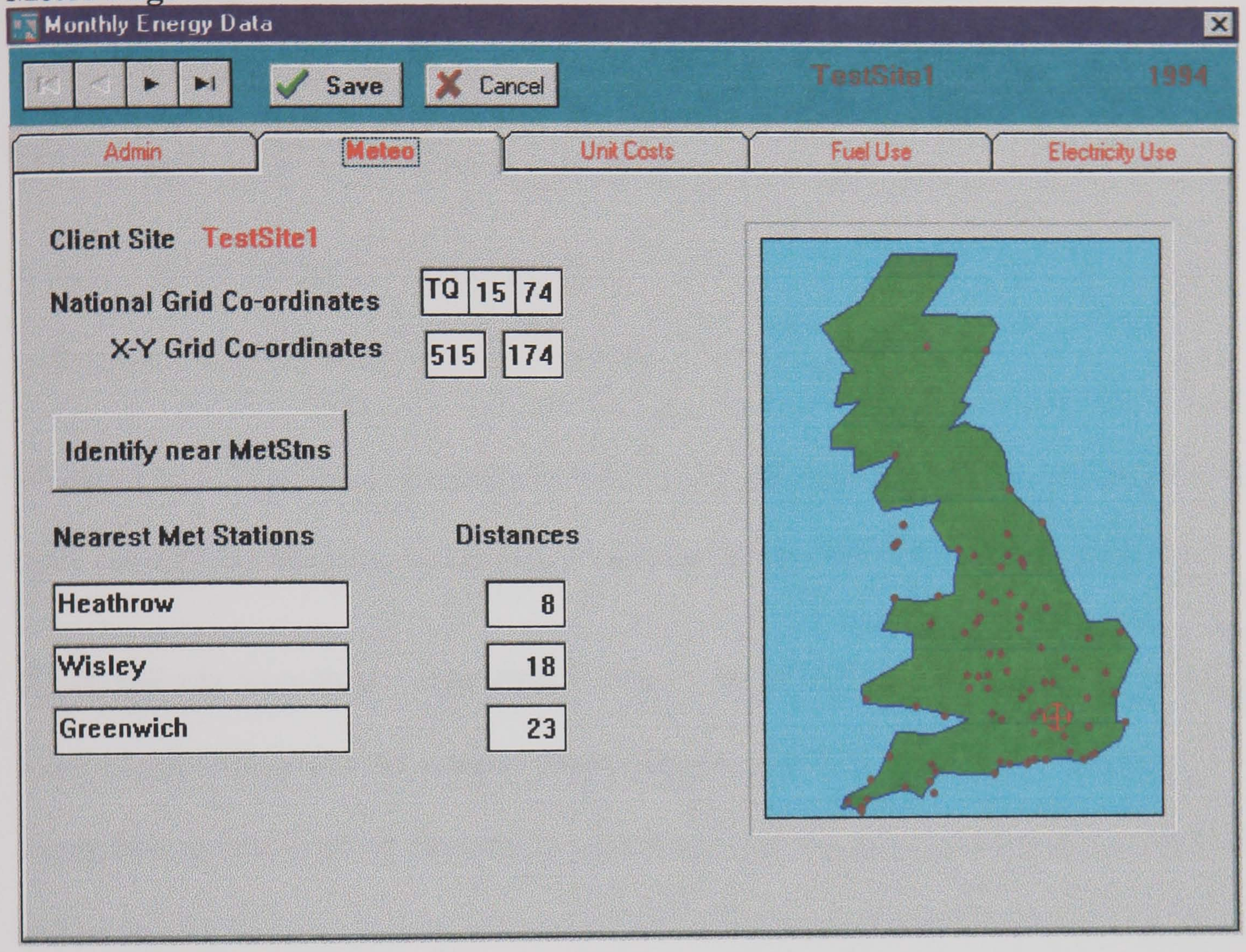
1. they will not all operate at the same time,

2. the load on all electrical circuits up to the motor will be reduced.

So Power factor correction cannot be adequately dealt with except where there is an intimate knowledge of electrical systems on a particular site. This makes it unsuitable for a generalised programme.

8.5 Monthly Consumptions

Meteo Page



The Meteo page

The Meteo page automatically identifies the nearest meteorological stations to the client site, based upon the National Grid Co-ordinates of the site, and calculates distances to the site from the three nearest Meteorological Stations. The National Grid co-ordinate can be found on Ordnance Survey maps and many road maps.

It may be appropriate in future development of the system to develop this aspect of the programme to work with commercial Geographical Information Systems, or even the Ordnance Survey Interactive Atlas of Great Britain.

8.5.1 Weather Data Mapping

Met Station data is mapped based upon the National Grid Reference. This can then be used to identify nearest stations to a site of interest, their distances from the site, etc. The map can be displayed using the computers graphics mode.

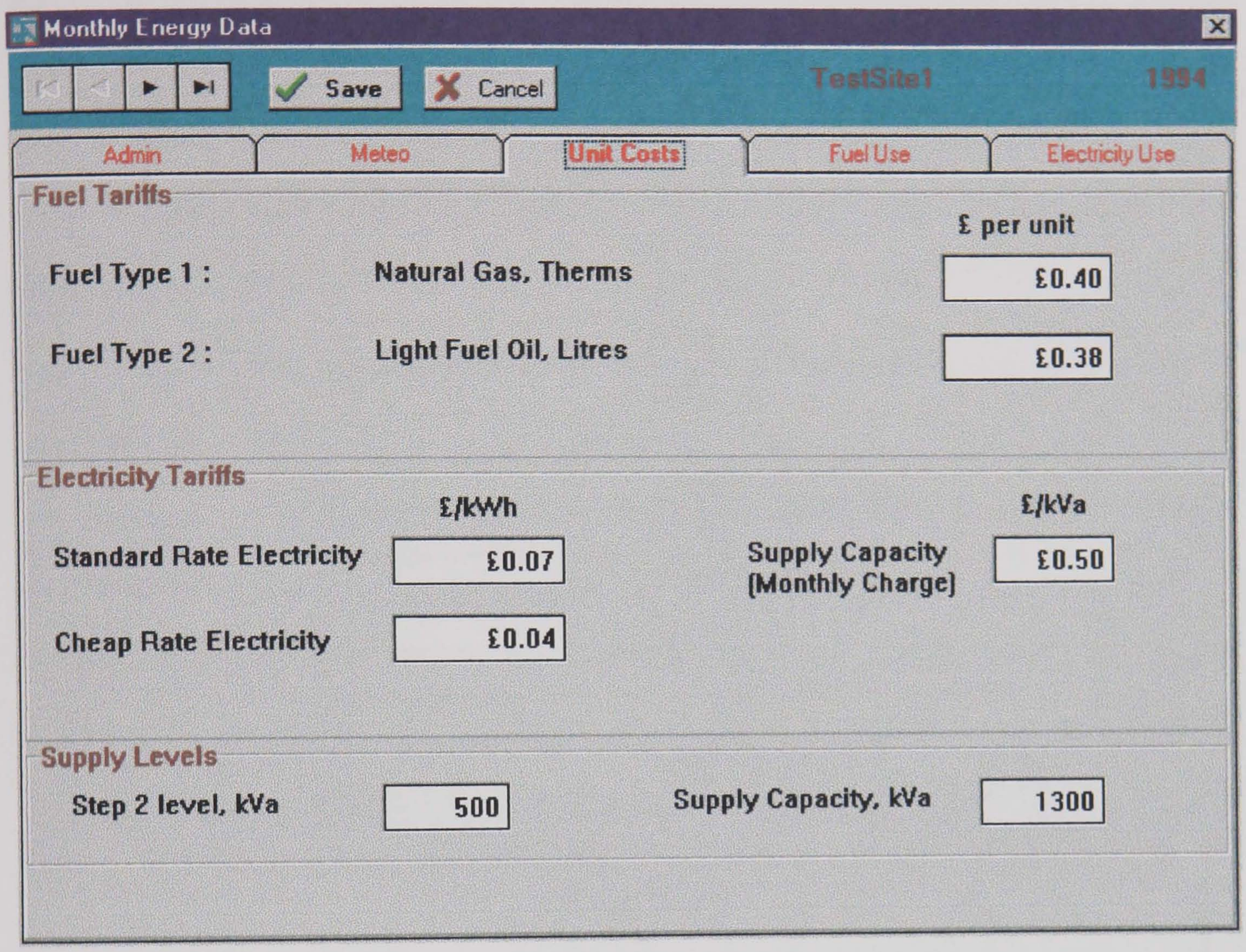
A routine NATOGRID has been developed, which converts the National Grid reference code to an X-Y co-ordinate with the origin based on the Scilly Isles.

When a Client Site's co-ordinates are entered the weather data site file is opened, the three nearest Met Stations are identified and their distances to the site are calculated.

If only one site were to be considered it would only be necessary to obtain the monthly weather data sheets for the nearest meteorological stations, but even in this case one would have to know which stations they were and their locations, distance from the site and so on.

This mapping procedure is likely to give very acceptable results in comparison to traditional approaches where Britain has been divided into 17 regions for degree days and 9 regions for meteorological purposes with average temperatures, frosts, insolation, rainfall, snowfall, and humidity used to estimate conditions on sites within a region.

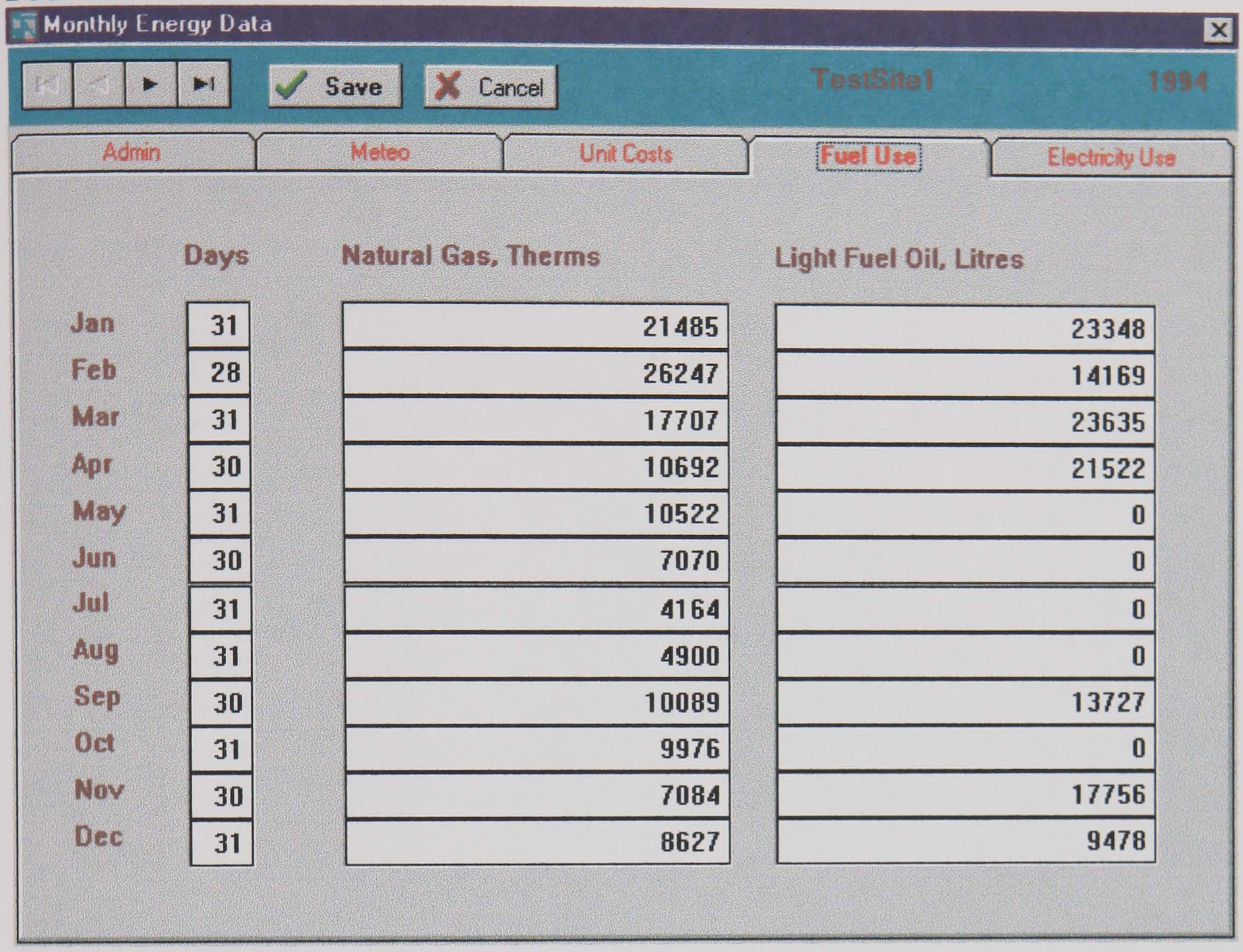
Unit Costs



The Unit Costs page

The Unit Costs page allows fuel and electricity tariff data for the site to be recorded.

Fuel Use

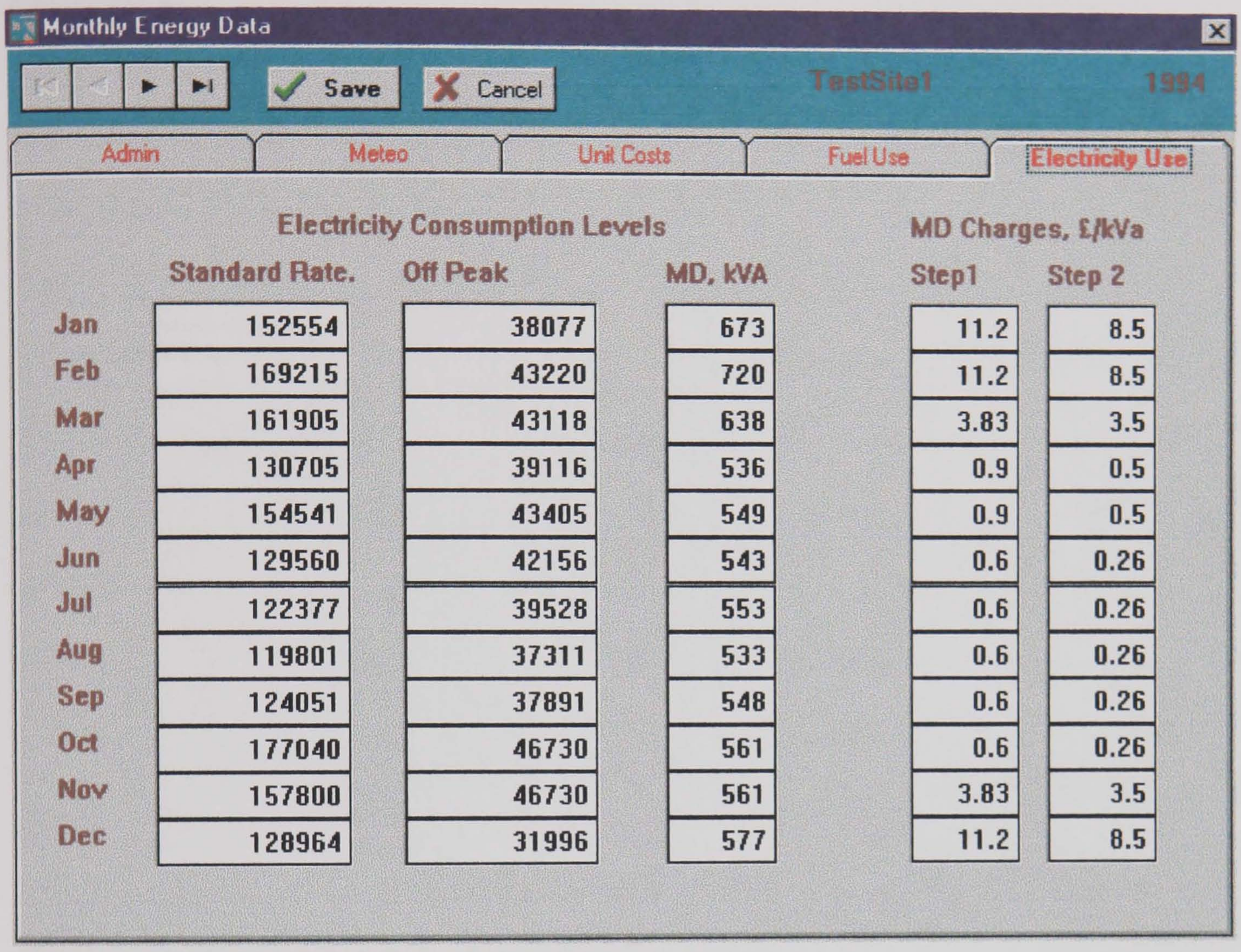


	Days	Natural Gas, Therms	Light Fuel Oil, Litres
Jan	31	21485	23348
Feb	28	26247	14169
Mar	31	17707	23635
Apr	30	10692	21522
May	31	10522	0
Jun	30	7070	0
Jul	31	4164	0
Aug	31	4900	0
Sep	30	10089	13727
Oct	31	9976	0
Nov	30	7084	17756
Dec	31	8627	9478

The Fuel Use page

The Fuel Use page allows the monthly fuel consumption figures and the number of days worked in each month to be recorded. The normalised energy consumption will later be automatically correlated against weather data from the met stations identified by the Meteo page.

Electricity Use



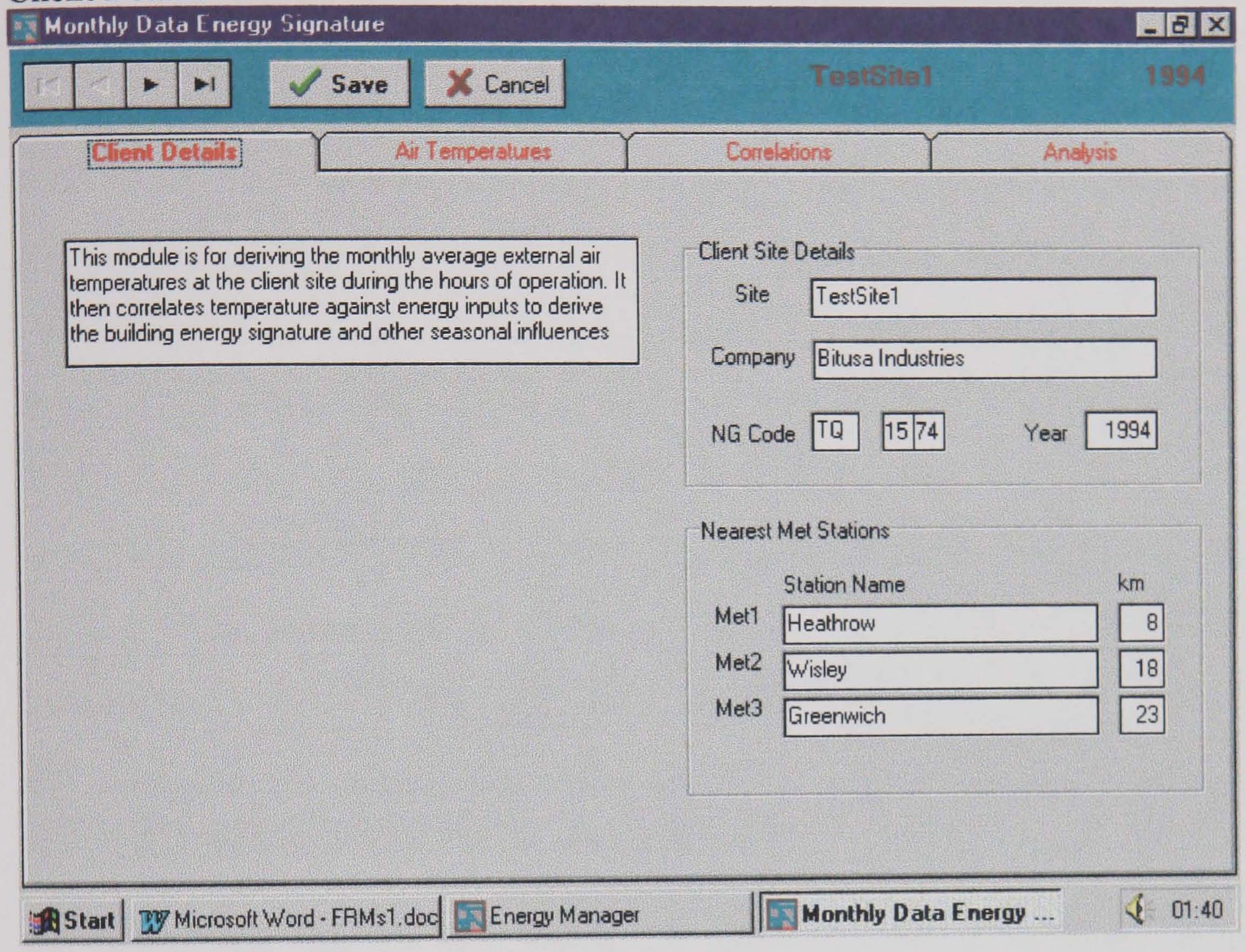
	Standard Rate.	Off Peak	MD, kVA	Step1	Step 2
Jan	152554	38077	673	11.2	8.5
Feb	169215	43220	720	11.2	8.5
Mar	161905	43118	638	3.83	3.5
Apr	130705	39116	536	0.9	0.5
May	154541	43405	549	0.9	0.5
Jun	129560	42156	543	0.6	0.26
Jul	122377	39528	553	0.6	0.26
Aug	119801	37311	533	0.6	0.26
Sep	124051	37891	548	0.6	0.26
Oct	177040	46730	561	0.6	0.26
Nov	157800	46730	561	3.83	3.5
Dec	128964	31996	577	11.2	8.5

The Electricity Use page

The Electricity Use page allows the monthly electricity consumption figures to be recorded, along with any season related charges. This approach is based upon the Best Practice Programme Fuel Efficiency Booklet 9, Economic Use of Electricity in Industry, London Electricity's booklet Electricity Prices for your Business, and Energy Management by Paul O'Callaghan. Unfortunately, since the programme was written the energy tariffs have changed and most businesses no longer pay on Maximum Demand based tariffs, but on variable rates depending on season and time of day. This can be approximated by averaging peak and off peak costs over the year, but the maximum demand information becomes redundant.

8.6 Energy Signature

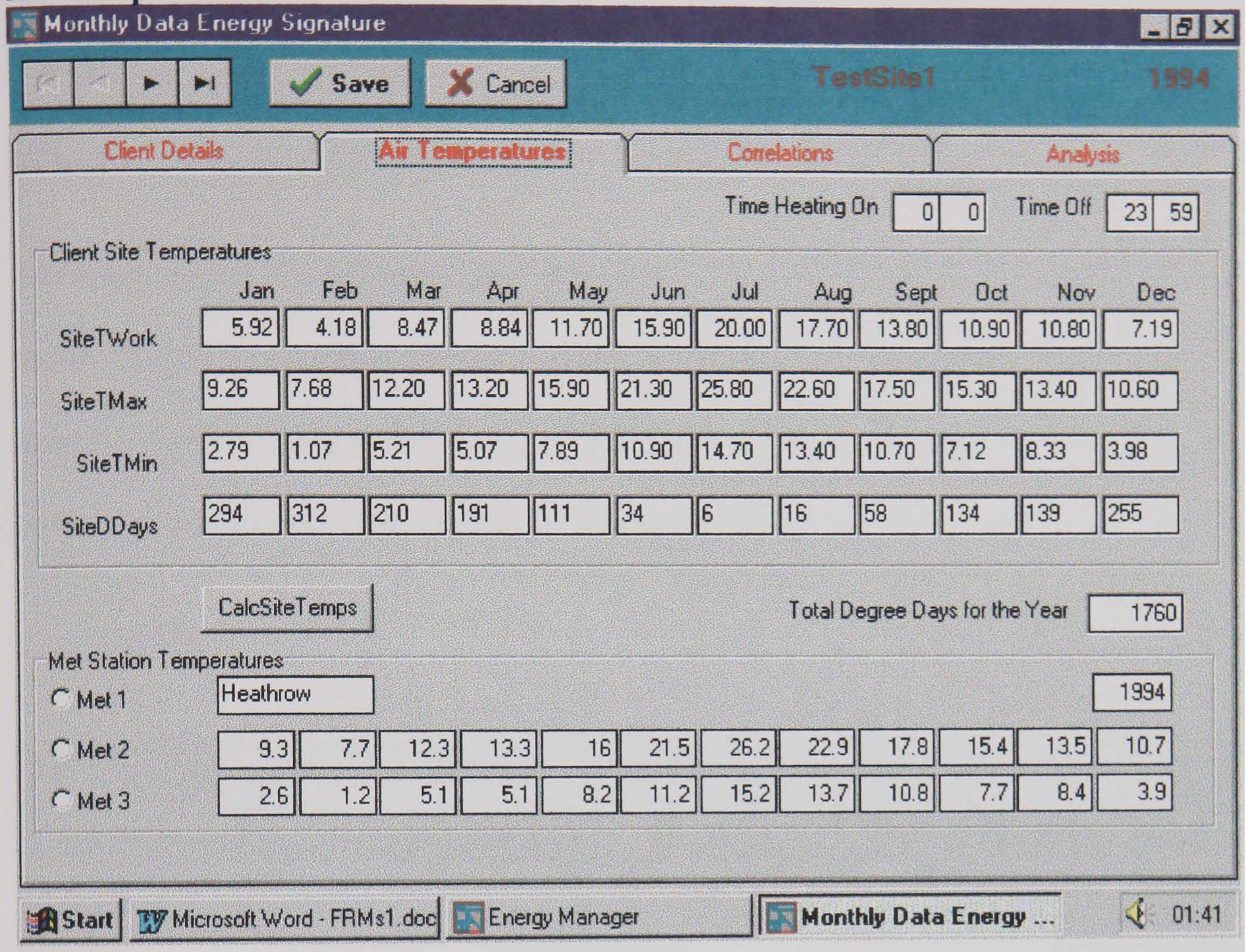
Client Details



The Client Details page

The Client Details page identifies the client and the meteorological stations which will be used for estimating air temperatures.

Air Temperatures



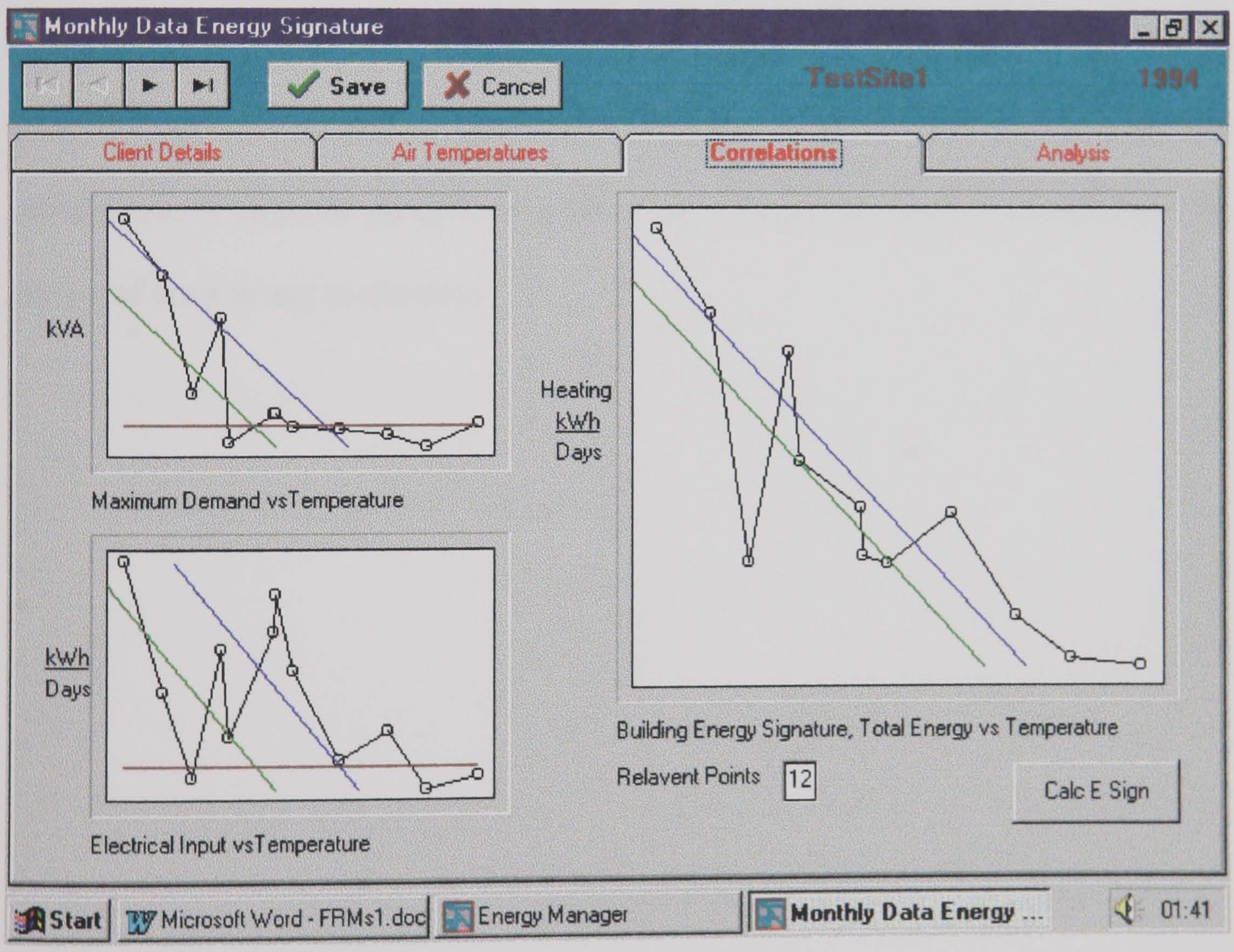
The Air Temperatures page

The weather data from the three nearest met stations is used by the programme to automatically estimate mean monthly maximum and minimum air temperatures for the client site using a weighted average method. From these the monthly degree days for the site are automatically calculated (for comparison by the user against other sources). The Site's location and the month are used by the programme to calculate dawn and dusk times, and these combined with the air temperatures are used by the programme to model a diurnal temperature curve for each month. The diurnal temperature curves are then chopped by the programme to give the air temperature during the working hours for the site (e.g. the mean air temperature between 9 a.m. and 5.30 p.m.). This is automatically corrected to allow for summer/winter time hour changes.

Multiple shifts during one 24 hour day are not a problem because they can be treated as one heating period, effectively the same as the heating system switching on and off a number of times during the heating period in response to a thermostat.

The temperatures for individual met stations can be viewed by the user to confirm that the calculated site temperatures are within a reasonable range (not necessary for the simple weighted average now being used, but useful with the more complex but less stable predictive method experimented with earlier in the development).

Correlations

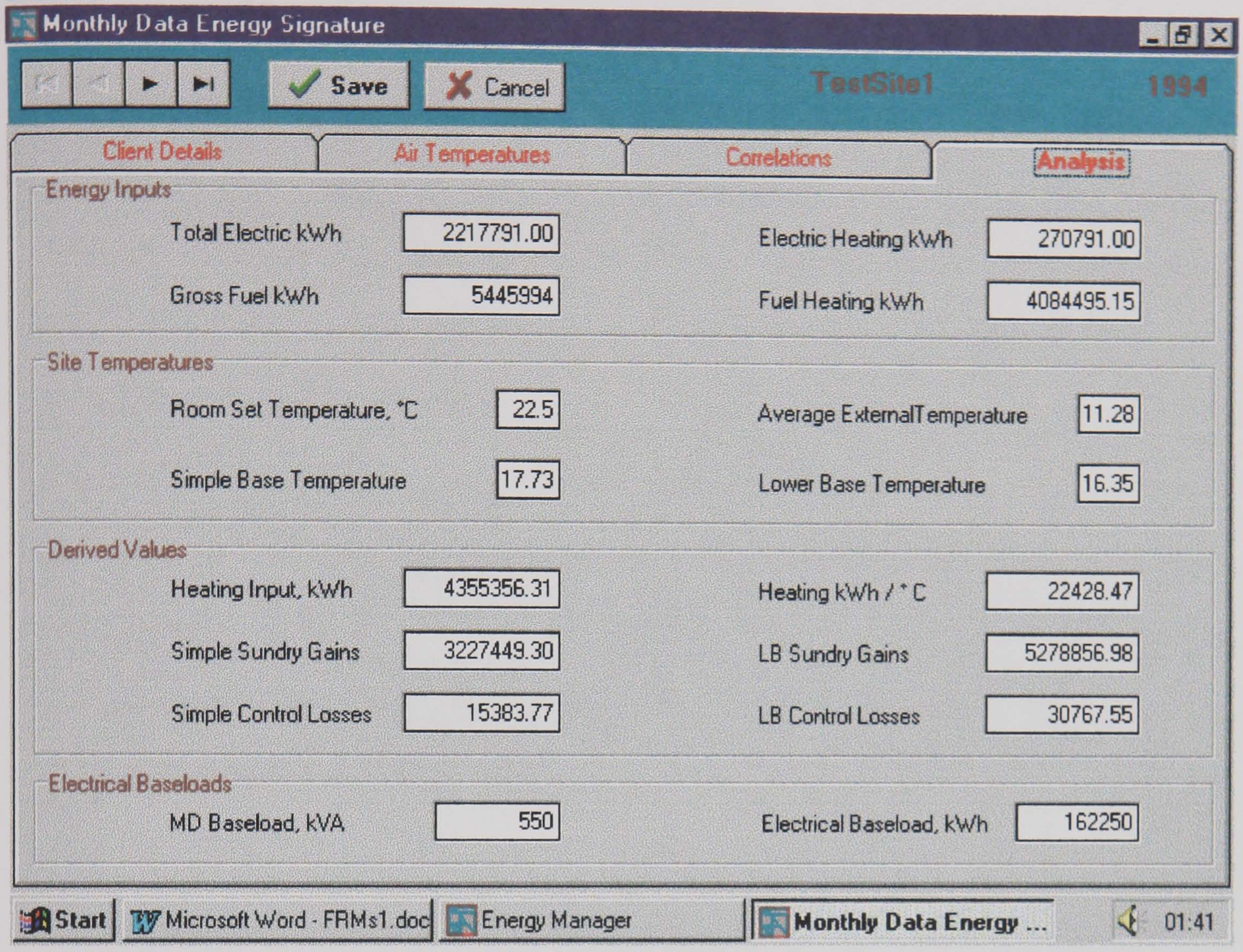


The Correlations page

The programme correlates calculated site temperatures against electrical maximum demand, electrical input, and total energy input to derive building energy signatures. A simple regression line is then automatically calculated for each graph.

On the assumption that the building was at least adequately heated most of the time, a second, parallel, line is plotted below the first. Initially this was set at an interval of one standard deviation of the data points from the simple regression line, but it was felt that this was not allowing enough caution for occasional un-reported inadequate heating, so the interval is now such that there is a greater than 95% chance that the building is being adequately heated if the heating/climate relationship follows the lower line. Although the lower line is shown and a lower base temperature calculated it was decided to err on the side of caution by using the original regression line for later calculations. It might be possible to develop the 95th percentile lines as estimates of the margin of error in any predictions.

Results

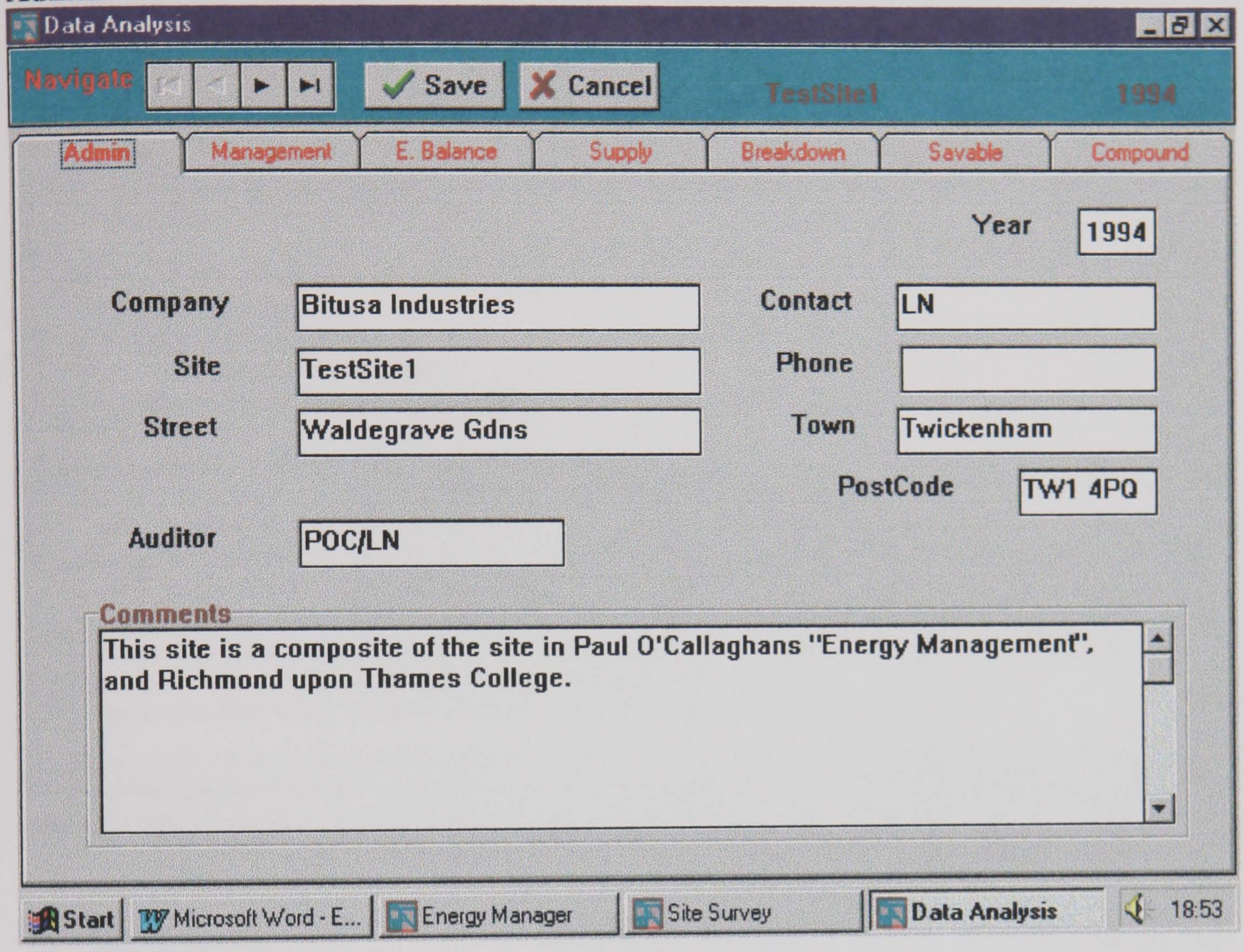


The Results page

The Results page automatically summarises the energy use data which the programme can infer from the building energy signature, based upon both the simple regression line and the lower (95% certainty) regression line.

8.7 Analysis Module

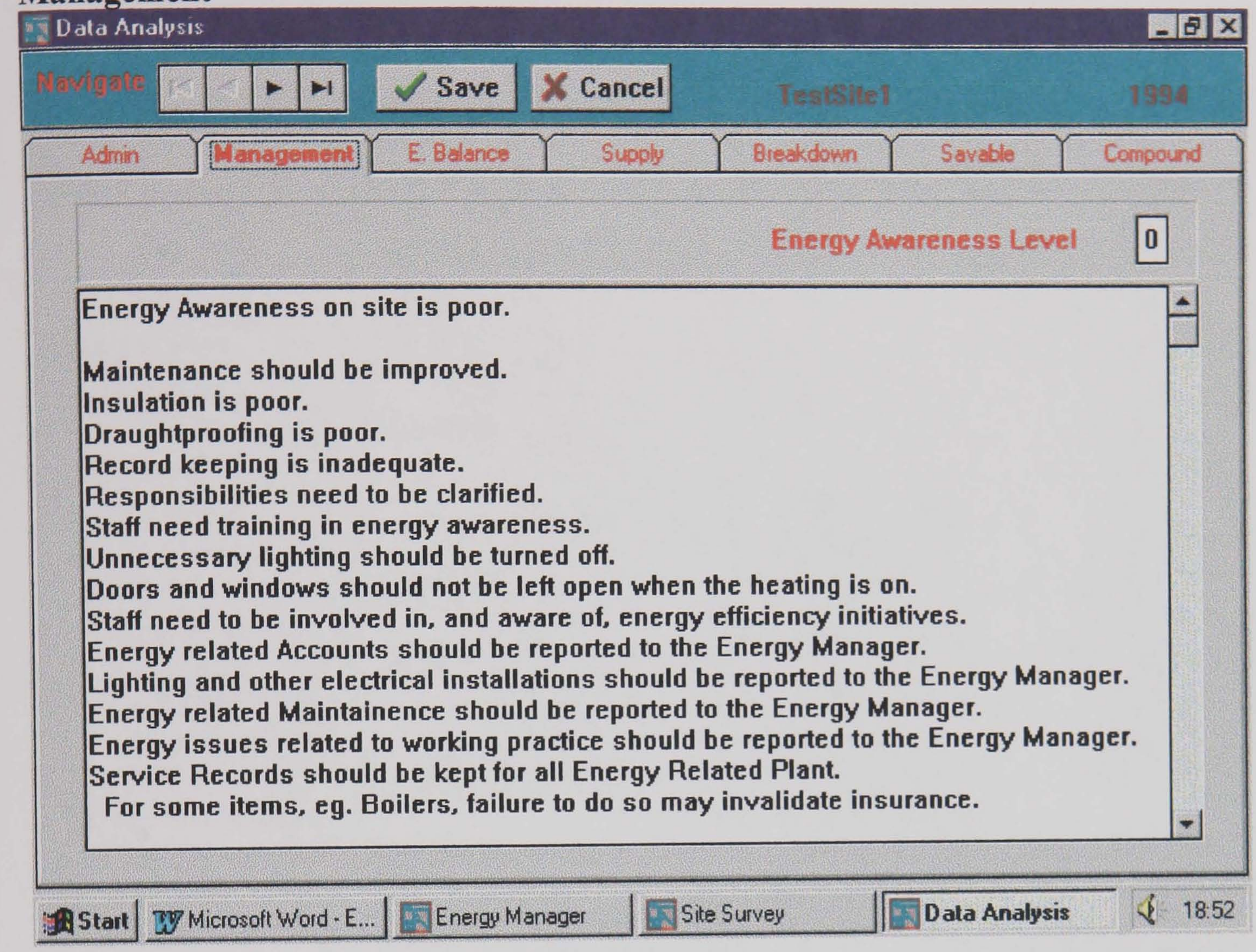
Admin



The Analysis Admin page

The Admin page identifies the site and displays any notes made by the auditor during the site survey in a scrollable memo box.

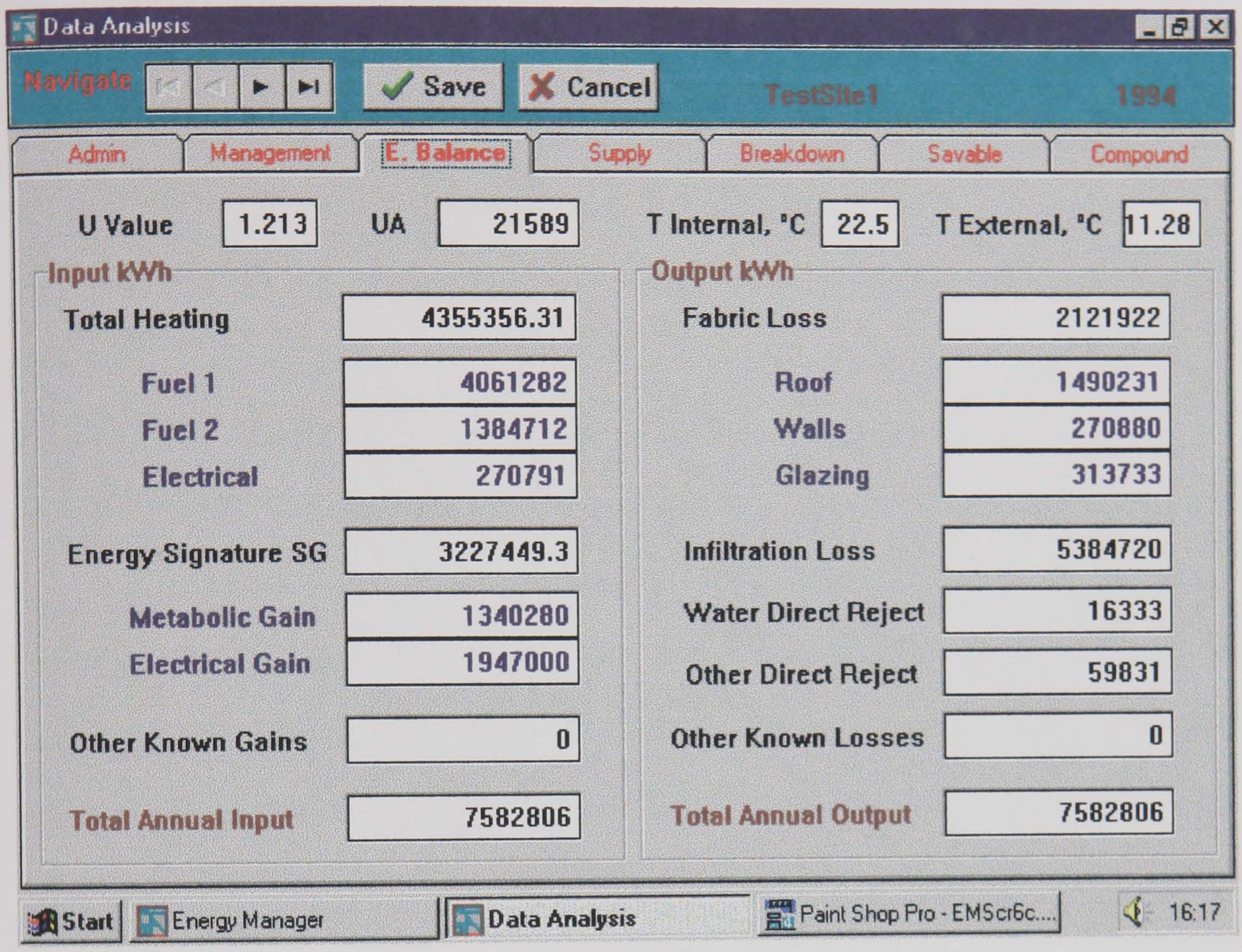
Management



The Analysis Management page

The Management page lists recommendations for improving the energy management structure and record keeping, made automatically by the programme from information recorded during the site survey. It also displays an energy awareness rating calculated by the programme, based upon the energy awareness checklist in the site survey module.

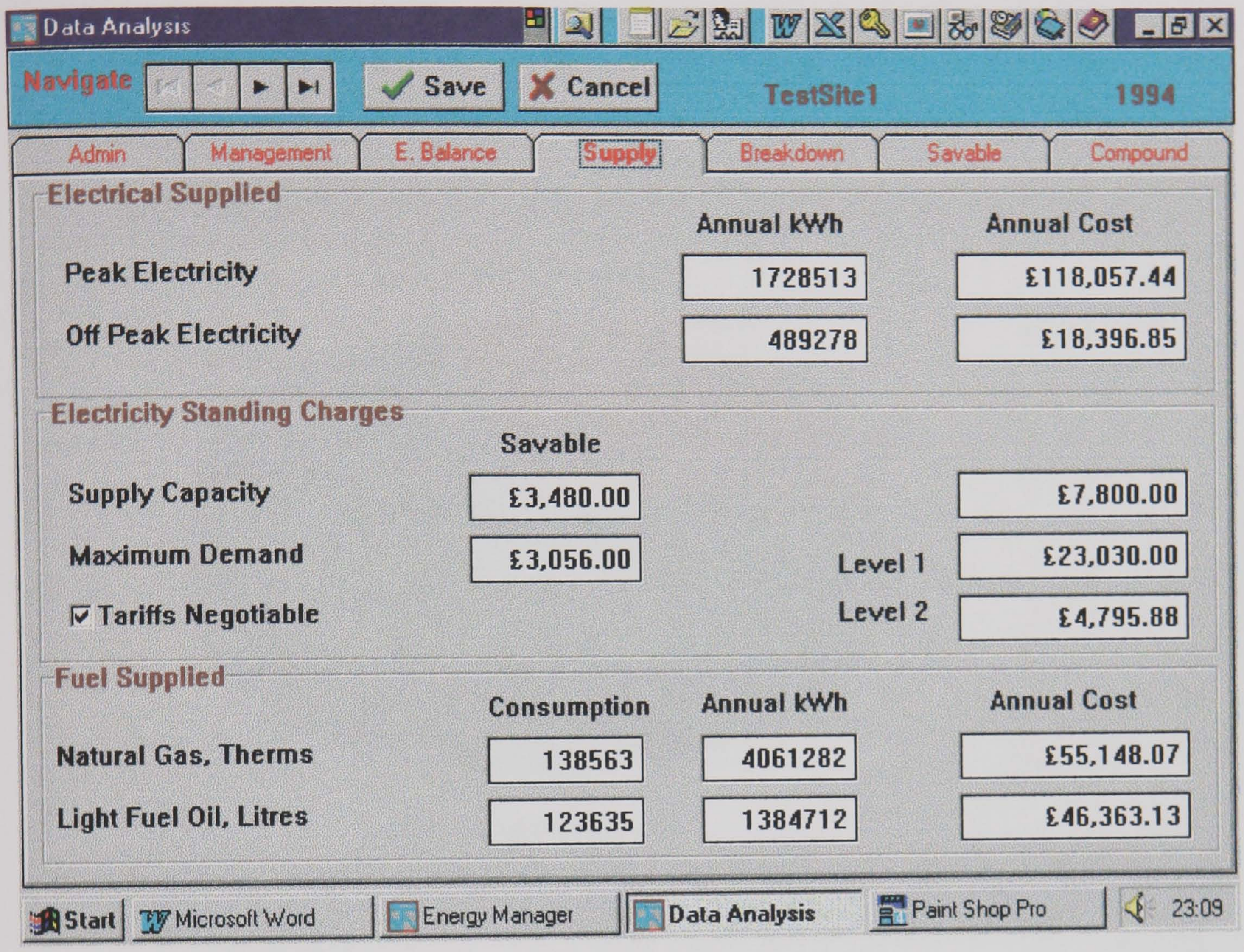
E. Balance



The E. Balance page

The E. Balance page shows the energy balance for the site calculated by the programme. Sub-components of a gain or loss (e.g. "Roof ") are printed in blue to distinguish them from the total (e.g. "Fabric Loss"), printed in black.

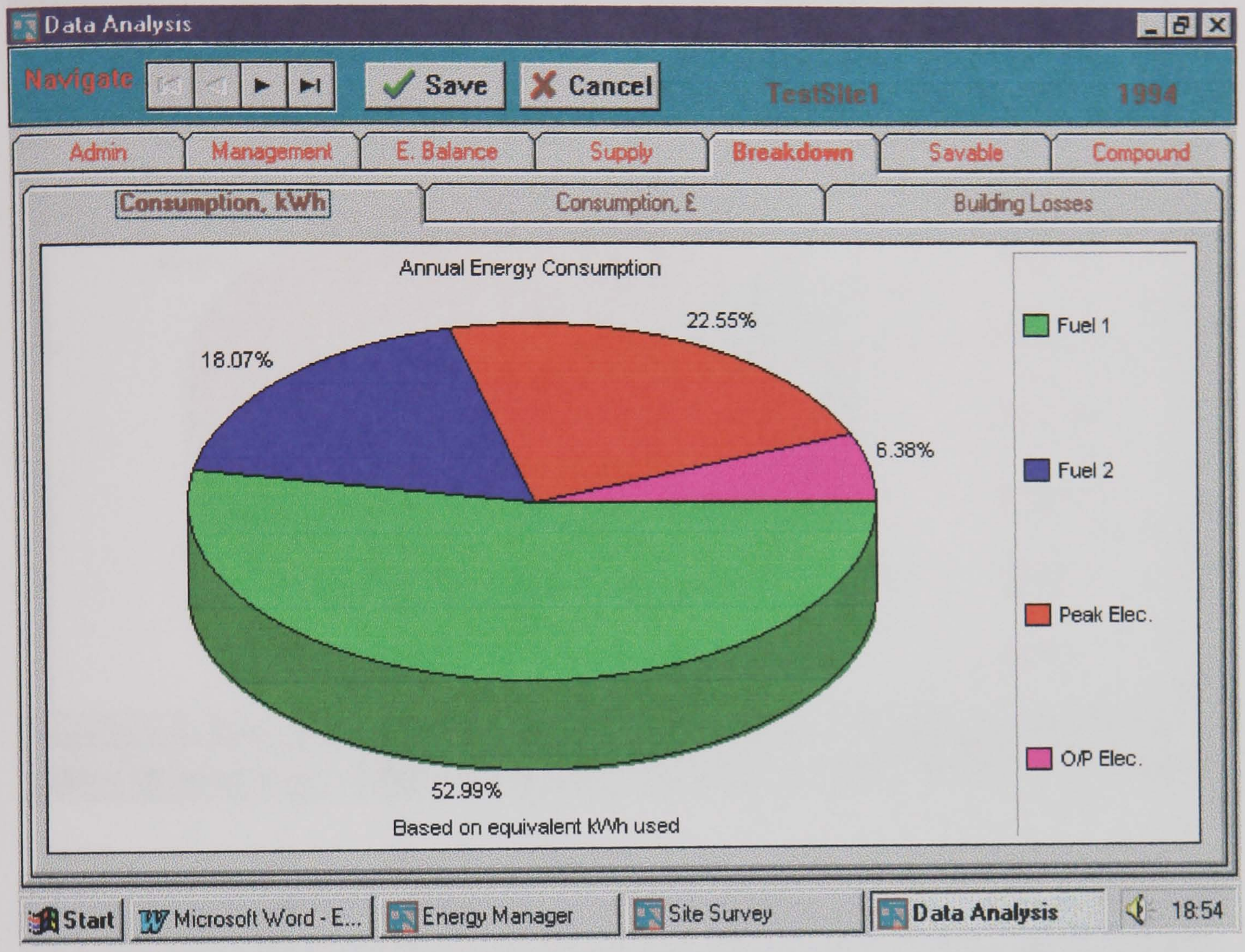
Supply



The Supply page

The Supply page displays a break down of the annual energy supplied in terms of Kilowatt-Hours and cost. The costs saveable from the Supply Capacity and Maximum Demand charges are identified.

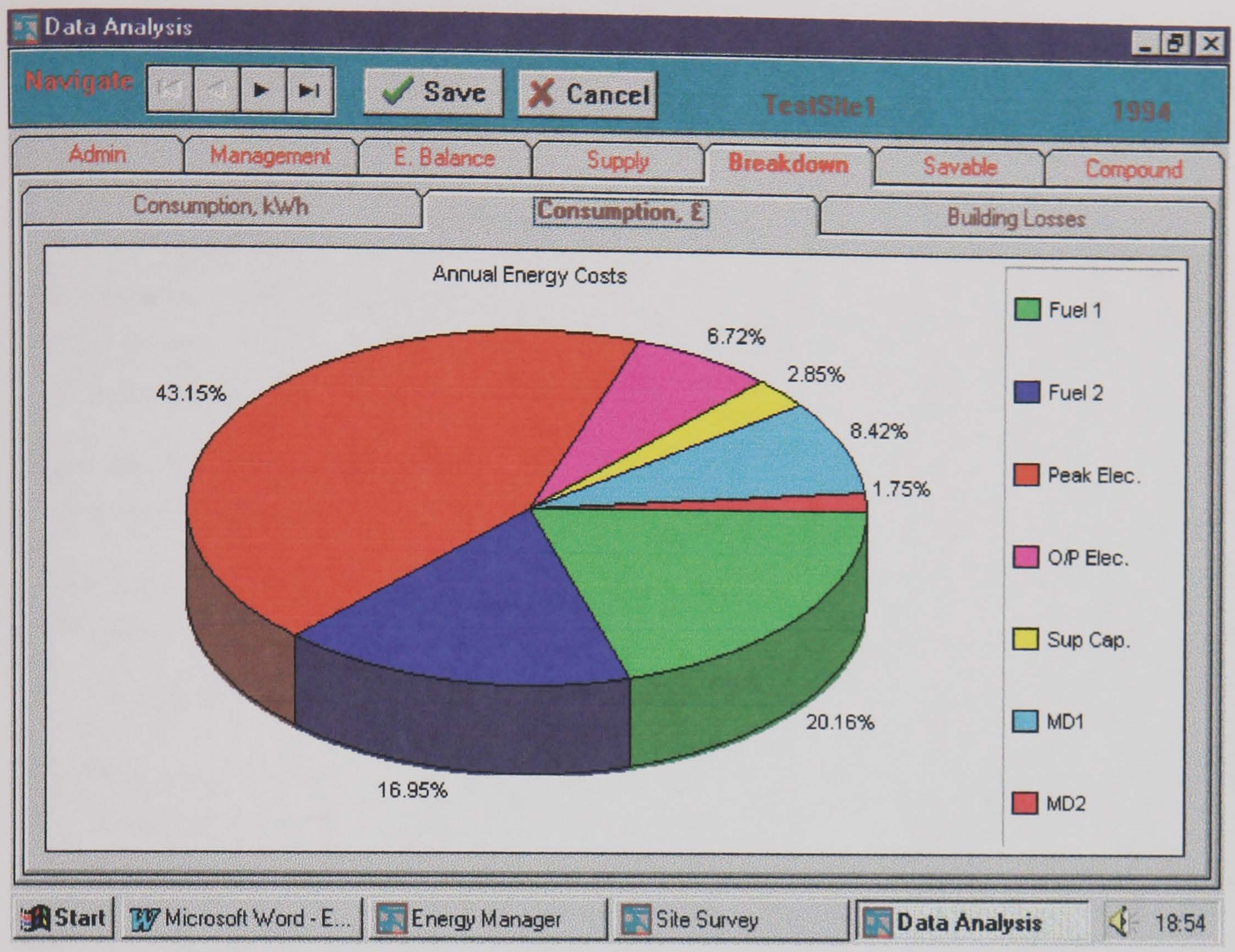
Breakdown



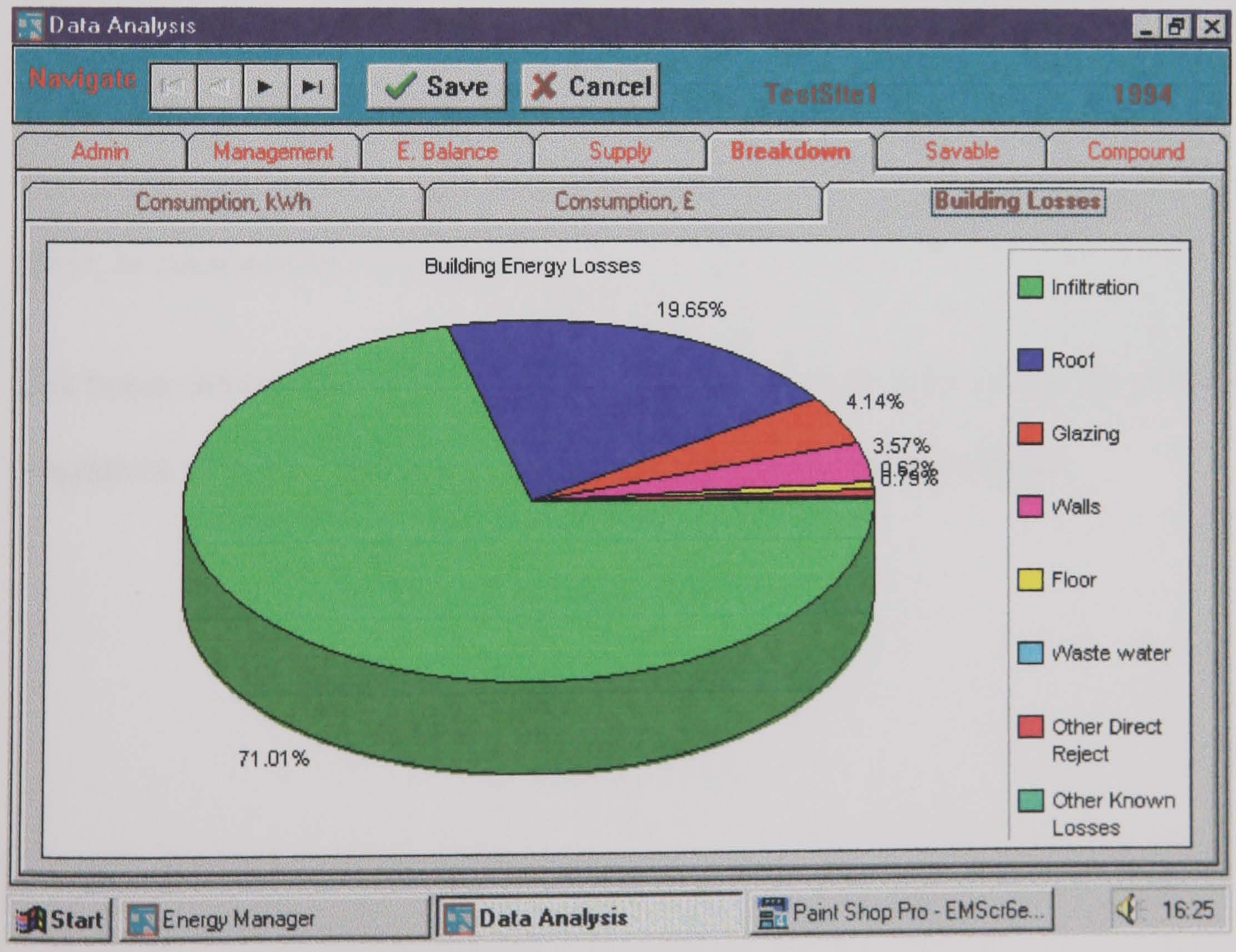
The Breakdown page

The Breakdown page automatically displays energy information in graphical form as pie charts. It has three sub pages for consumption in kWh, consumption costs in £, and building losses.

Double clicking on a segment of the chart brings up an information bubble, identifying the component, it's quantity, the total figure, and the percentage of the total that the segment represents.

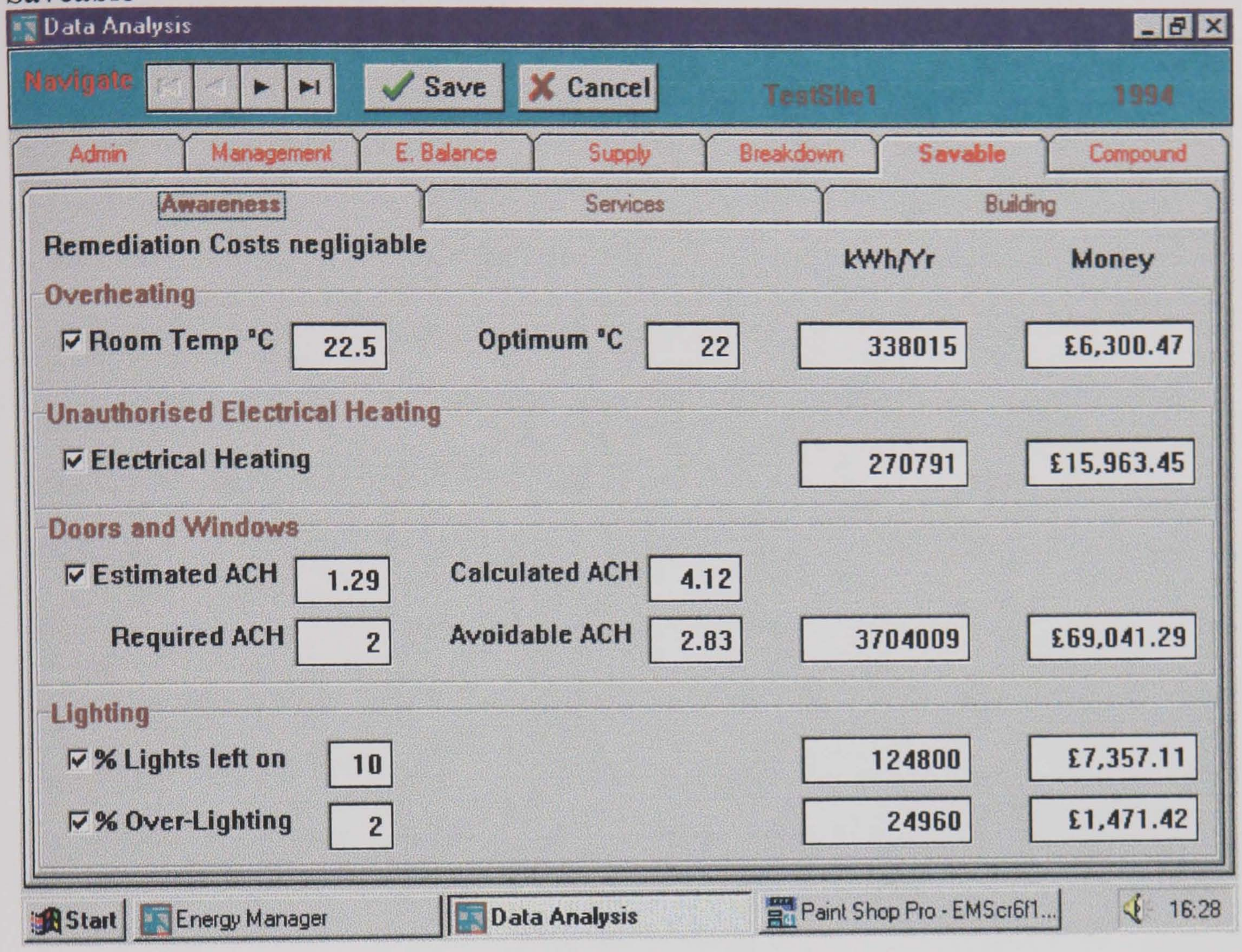


Data Analysis
Navigate
Save
Cancel
TestSite1
1994
Admin
Management
E. Balance
Supply
Breakdown
Savable
Compound
Consumption, kWh
Consumption, £
Building Losses
Annual Energy Costs
6.72%
2.85%
8.42%
1.75%
43.15%
20.16%
16.95%
Fuel 1
Fuel 2
Peak Elec.
O/P Elec.
Sup Cap.
MD1
MD2
Start
Microsoft Word - E...
Energy Manager
Site Survey
Data Analysis
18:54



Data Analysis
Navigate
Save
Cancel
TestSite1
1994
Admin
Management
E. Balance
Supply
Breakdown
Savable
Compound
Consumption, kWh
Consumption, £
Building Losses
Building Energy Losses
19.65%
4.14%
3.57%
71.01%
Infiltration
Roof
Glazing
Walls
Floor
Waste water
Other Direct Reject
Other Known Losses
Start
Energy Manager
Data Analysis
Paint Shop Pro - EMScr6e...
16:25

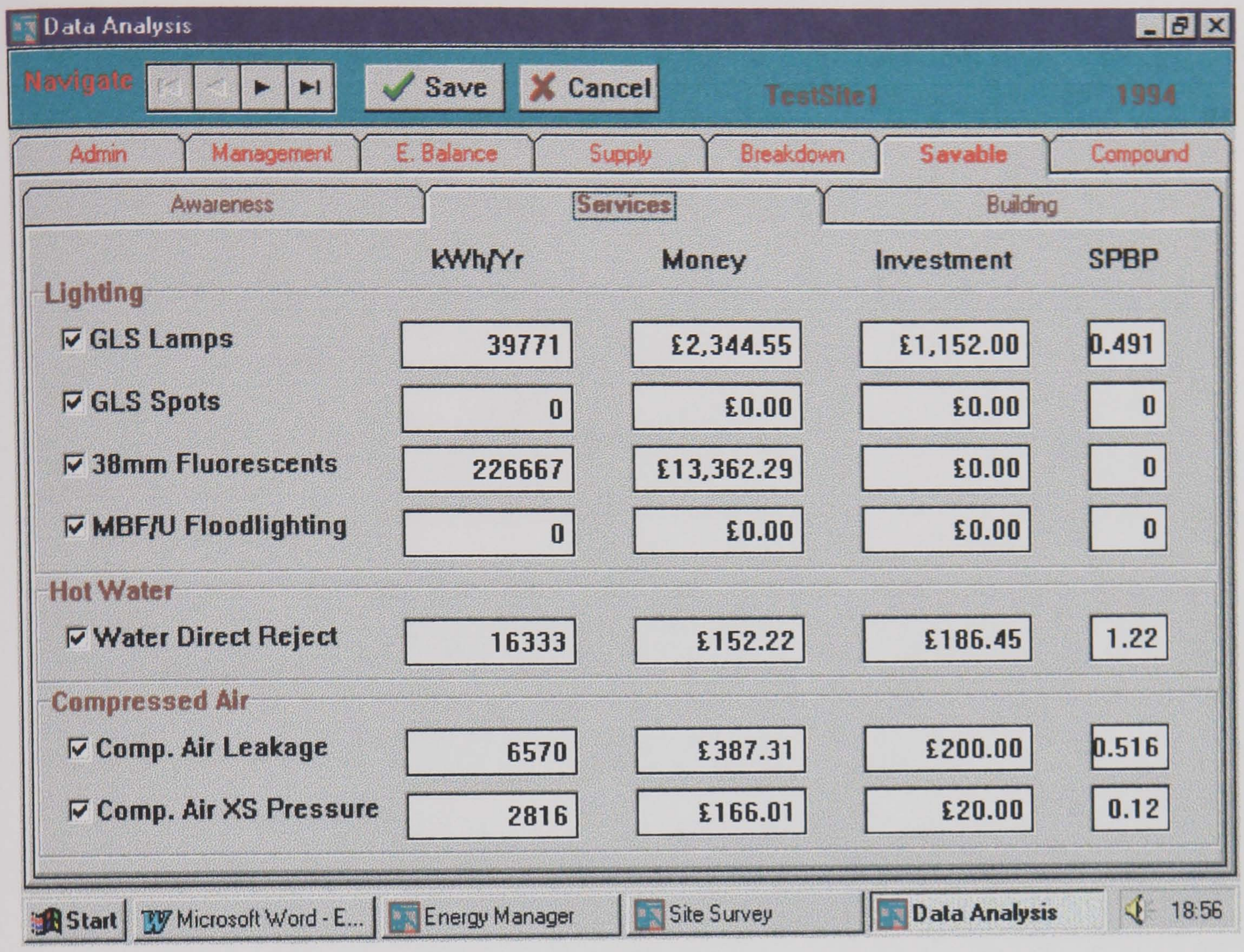
Saveable



The Saveable page

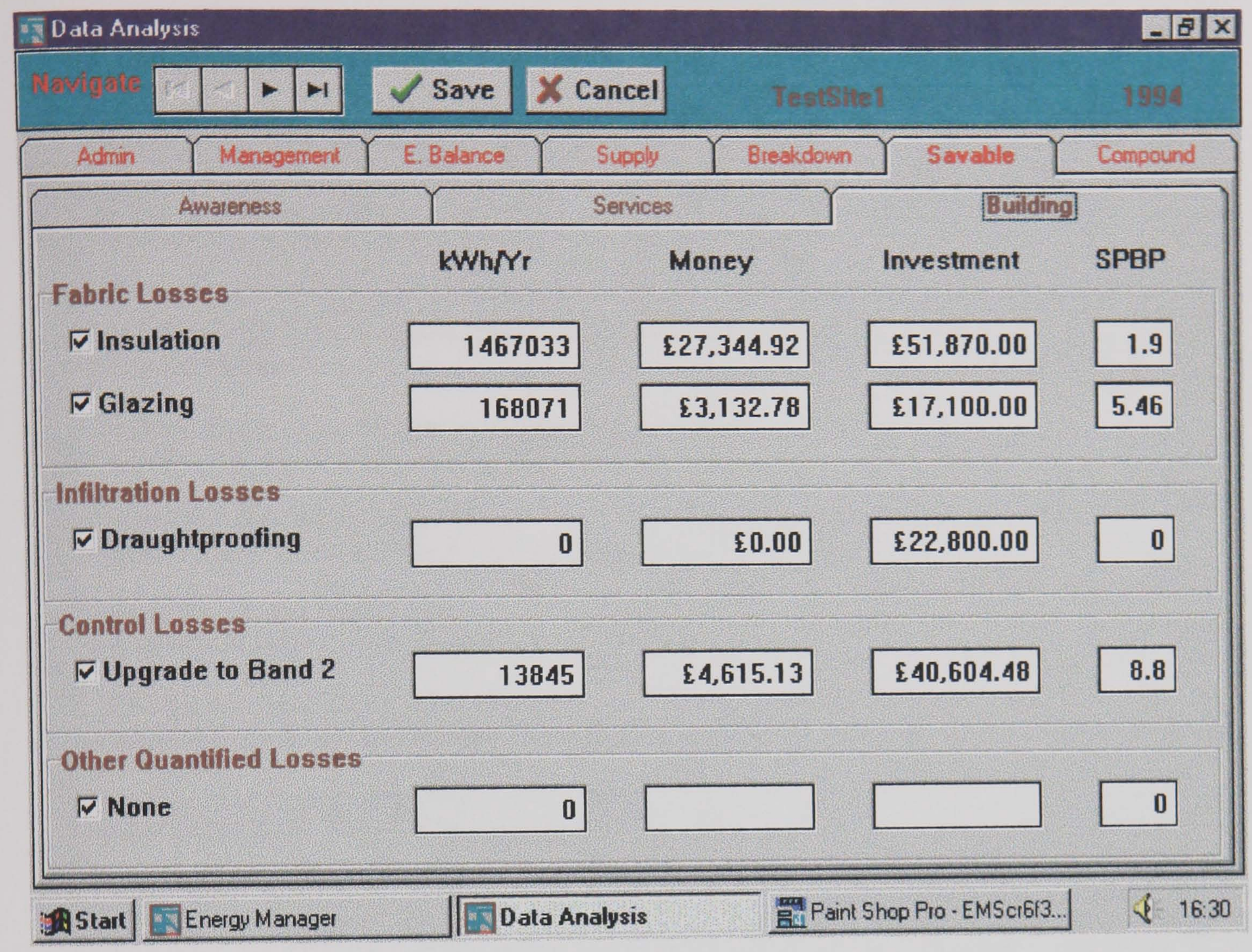
The Saveable page has three sub-pages for displaying the stand alone savings possible from improved awareness, improvements to services, and improvements to the building fabric, as calculated by the programme.

Tick boxes can be used by the human energy manger to indicate whether he wants the programme to include that option in its calculations of compound savings.



The Services sub-page

The Services sub-page shows the potential savings, investment costs, and pay-back periods for improvements to the Lighting, Compressed Air, and Domestic Hot Water Systems

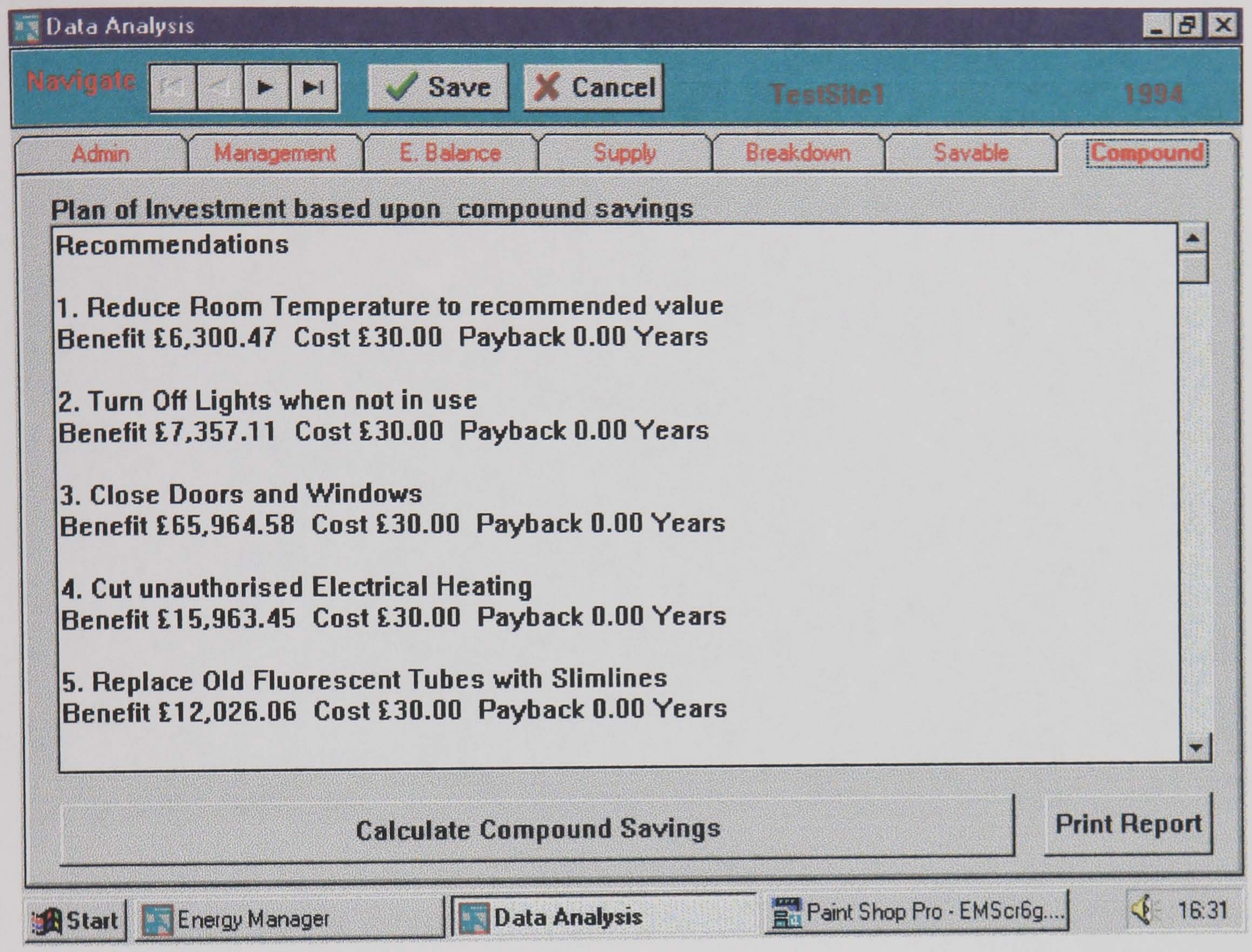


The Building sub-page

The Building sub-page shows the stand alone savings with associated costs and pay-backs for low cost / fast pay-back measures such as loft insulation, draught proofing, improved control systems, and any other quantifiable major loss identified during the site survey. Investment costs for Insulation, double glazing, and draught-proofing are estimated from typical costs quoted by an architect and a builder who specialise in refurbishing older buildings.

The estimated Controls upgrade investment cost is derived from Building Standards and EEO literature. A “Level 2” control system should give less than 10% control loss. Upgrading to “Level 2” from “Level 1” costs about 20% of the original annual control loss cost, from “Level 0” 30%, and from “Level -1” 50%.

Compound

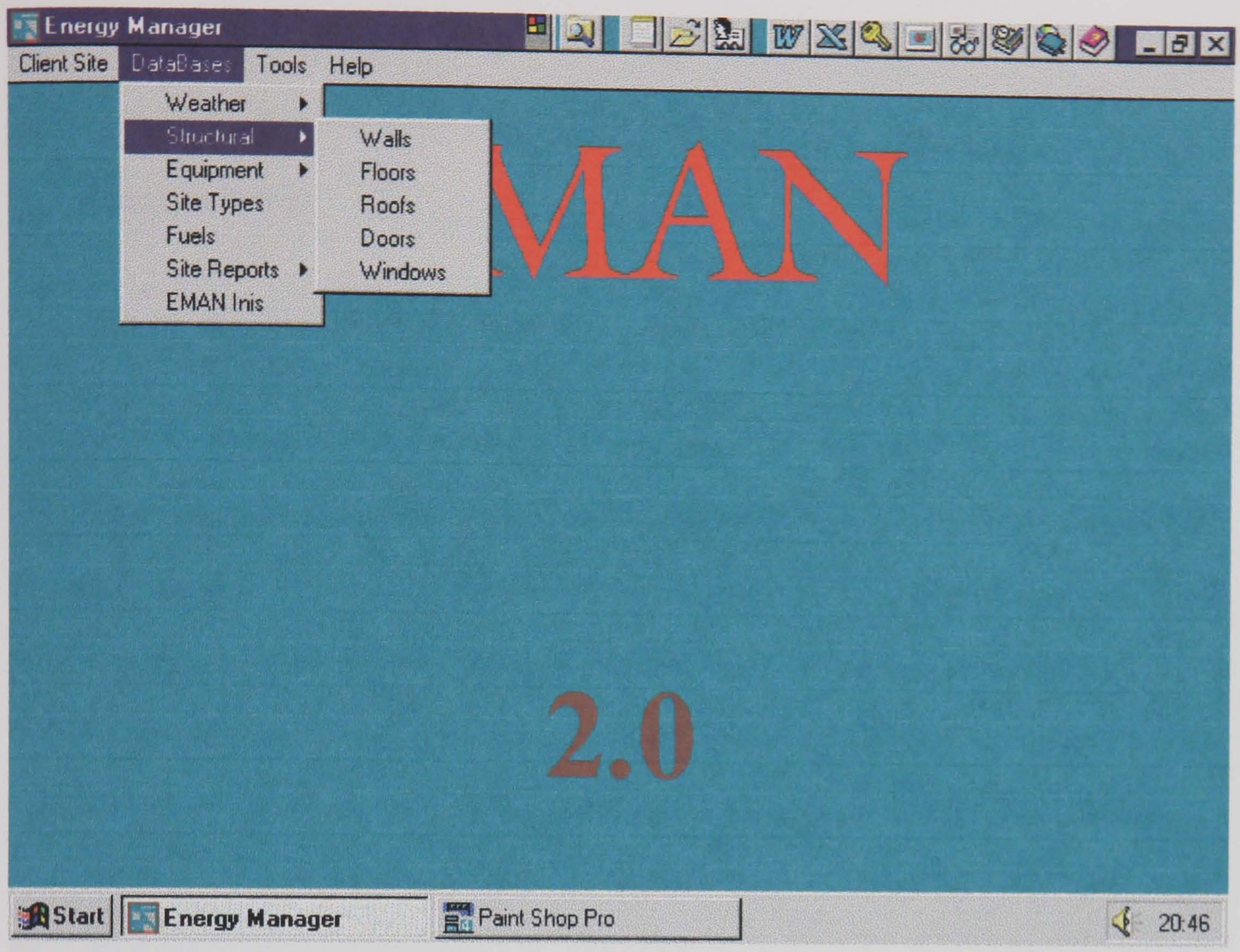


The Compound page

The Compound page automatically proposes a plane of investment by ranking those stand alone measures ticked on previous pages by pay-back period and automatically compensating for any knock-on effects which one improvement might have on the others.

8.8 Databases

There are also a number of forms for entering and editing building types, constructions, etc., in the database, but it is not necessary to discuss them individually or in detail at this time and so only one database input screen is shown as an example (though another has been illustrated previously in the discussion of the Structural survey).



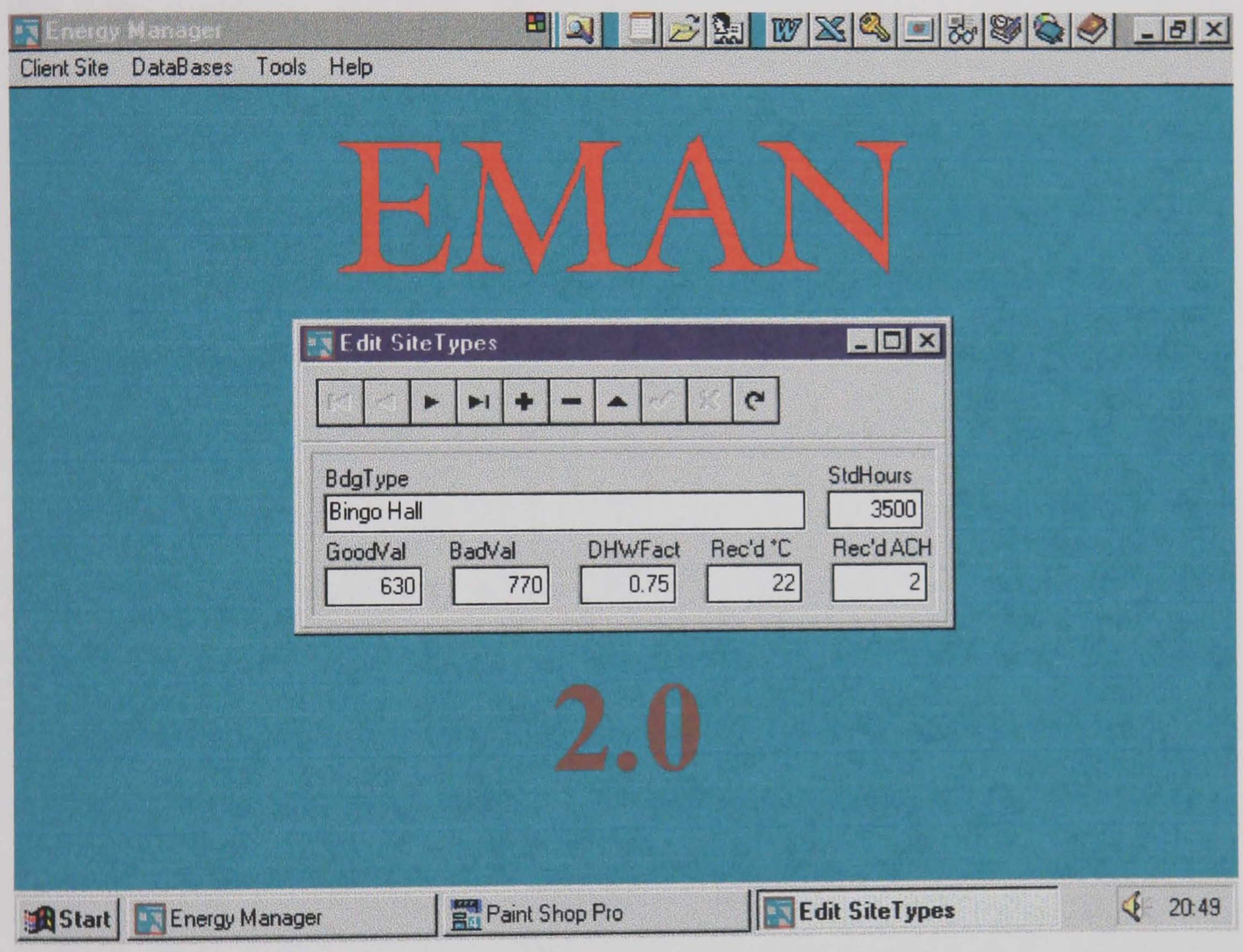
Accessing the Database Tables.

The databases can be accessed from the Main Screen by pull down menus. The databases include tables of Meteorological Stations, giving their name, National Grid Reference, and Altitude, and of Met Data, giving the station name, monthly maximum and minimum temperatures for a particular year. This allows stations close to the client site to be identified from all available meteorological stations, but the weather data only needs to be bought and entered for those stations and years which are relevant to a particular client site.

Structural data tables for Walls, Floors, Roofs, Doors, and Windows allow the construction details and u values of different structural components to be recorded. For example, Solid Brick Walls, Cavity Walls, Insulated Cavity Walls, etc. Where a new construction is encountered its details can be recorded in the data base.

A library of construction types is thus built up from which the relevant information can be pulled down and automatically entered into the energy management programme during the site survey.

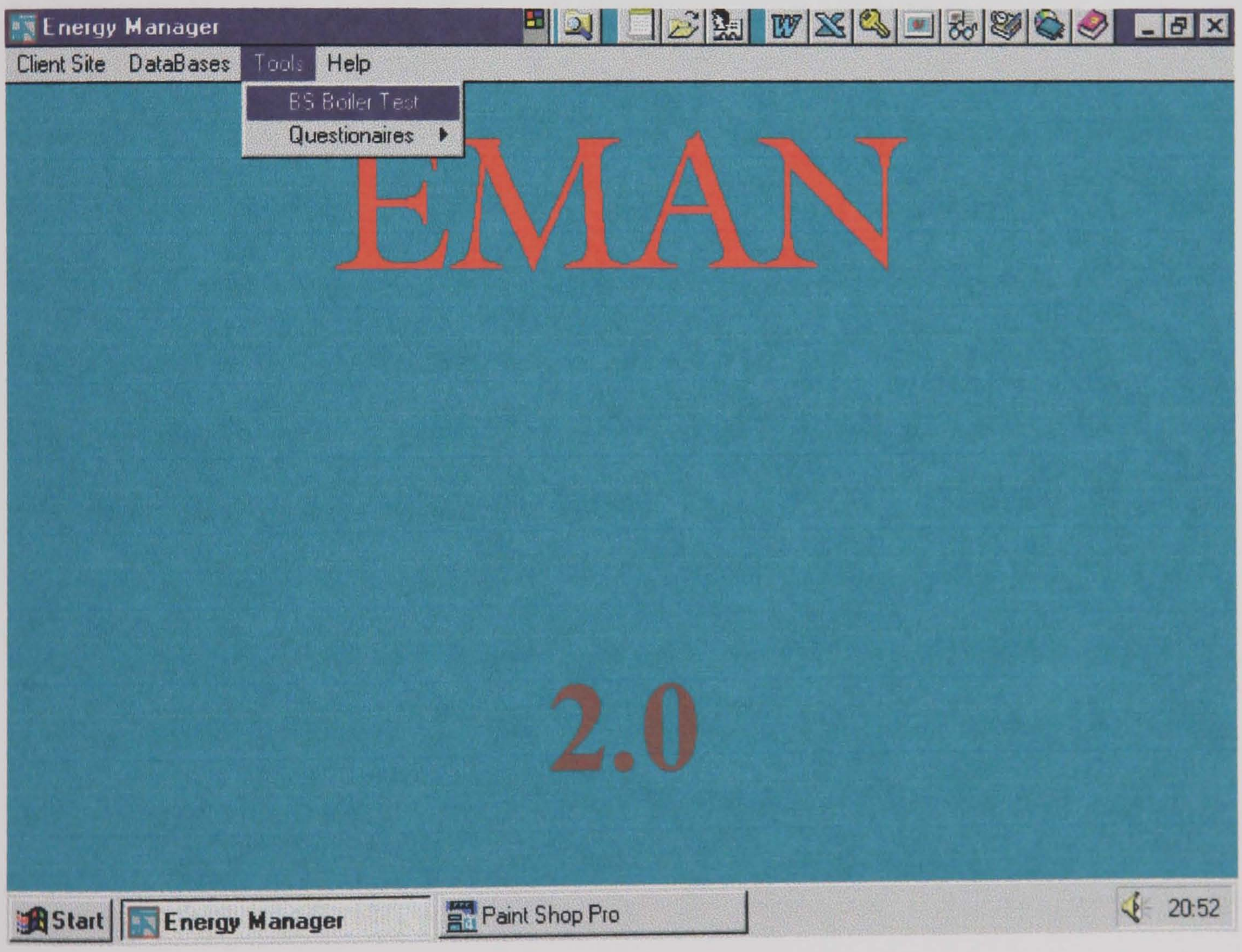
Similarly an editable and expandable data base table of fuel types allows the type of fuel, units used , and the kWh per unit to be recorded.



Editing the Site Types Database Table.

The Edit Site Types form allows the Site Types database to be expanded, edited, and modified. The Site Types database contains data fields for Good and Bad NPI values, the recommended ACH and room temperature, typical annual working hours, and a factor[1] for calculating the percentage of heating input which is used for Domestic Hot Water services.

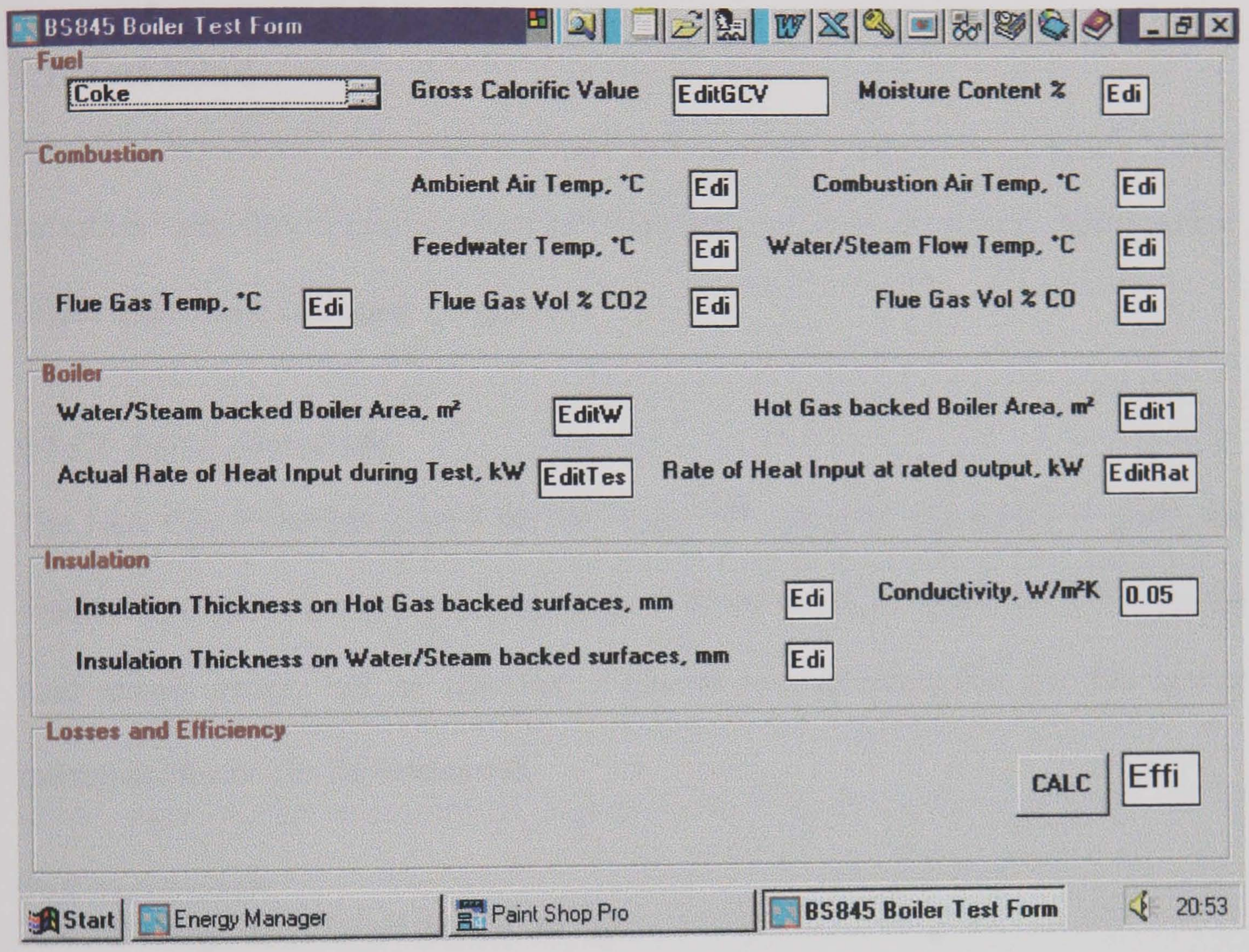
New records of Site Types can be added and the data in old records changed as fresh information becomes available. The only real limit on the number of different types which can be included is the availability of site type information and the amount of hard disc space available. The same applies to the other databases of construction types, meteorological data, etc.



Additional tools can be developed and included in the programme.

[1] This is the factor used in the Best Practice NPI calculation sheet, 0.75 means that 75% of the energy input is *not* used for hot water. It would seem more straight forward to change the equation slightly making this factor 0.25 to represent the 25% of heating input which is used for DHW generation.

The modular nature of the programme allows extra tools to be developed and compiled into the energy management package as it evolves. At present there is an additional tool for doing Boiler Efficiency calculations accessible from the Main Screen.



The Boiler Efficiency Calculator.

The Boiler Efficiency calculator is based upon the concise method of Boiler Testing given in B. S. 845.

There is no database behind this tool, the information entered is not stored within the programme but simply entered and used for the calculation. The development was undertaken in this manner to allow the Boiler Efficiency calculator to be distributed separately as a stand alone tool, either commercially or for promotional purposes. Making it simple, small, and self contained meant that it could be distributed easily on floppy discs and minimises potential installation or set-up problems.

9. TESTING THE ENERGY MANAGEMENT PROGRAMME

The prototype programme was tested on a synthetic data-set drawn from the manual audits conducted, and with real data from a large tertiary college.

9.1 Test Site 1

A model "Test Site 1" was created, which was based on sites audited, and the "Bitusa Industries" site from Professor Paul O'Callaghan's textbook on Energy Management. Bitusa itself was based upon a real site.

9.1.1.1 Initial Assessment

The New Client module gave Test Site 1 an NPI rating of 481 which is poor, and estimated possible low and no cost savings of between £41,331 and £111,185 from the total annual energy bill of £280,000. EMAN recommended that the full energy management exercise be carried out.

Full Assessment:
The full energy audit found the following:

U value : 1.213 Base Temperature : 17.7°C

9.1.1.2 Energy Management

Energy Awareness on site was rated as poor by the programme, which made the following observations in the "Management" analysis:

- Maintenance should be improved.
- Draughtproofing is poor.

- Record keeping is inadequate.
- Responsibilities need to be clarified.
- Staff need training in energy awareness.
- Unnecessary lighting should be turned off.
- Doors and windows should not be left open when the heating is on.
- Staff need to be involved in, and aware of, energy efficiency initiatives.
- Energy related Accounts should be reported to the Energy Manager.
- HVAC operations should be reported to the Energy Manager.
- Lighting and other electrical installations should be reported to the Energy Manager.
- Energy related Maintenance should be reported to the Energy Manager.
- Energy issues related to working practice should be reported to the Energy Manager.
- Service Records should be kept for all Energy Related Plant. For some items, e.g. Boilers, failure to do so may invalidate insurance.

9.1.1.3 Energy Use Breakdown

Fuel	Percentage of Total kWh	Percentage of Total Cost
Gas	52.99 %	20.16 %
Oil	18.07 %	18.07 %
Peak Electricity	22.55 %	43.15 %
Off Peak Electricity	6.38 %	6.72 %

In addition, standing charges were 2.85% of the total cost for Supply Capacity, 8.42% for Maximum Demand level 1, and , 1.75% for Maximum Demand level 2.

71% of the building heat loss was due to infiltration, corresponding to 4.12 ACH. The programme estimated that closing doors and windows would reduce this to 1.29 ACH. Since the recommended figure is 2 ACH for this type of site there is no point in worrying about further draught proofing, so this can be unchecked when calculating compound savings.

9.1.1.4 Stand Alone Savings Possible

From improved Energy Awareness :

Measure	kWh Saveable	£ Saveable
Reduce room temperature	338015	6,300
Cut out Electrical Heating	270791	15,963
Close Doors and Windows	3704009	69,041
Turn off unused Lights	124800	7,357
Reduce lighting levels	24960	1471

From improved Services :

Measure	kWh Saveable	£ Saveable	£ Investment	SPBP (Years)
Replace GLS with compact fluorescent	39,771	2,344	£1,152	0.49
Fit 22m ES fluorescent tubes	226,667	13,362	0	0
Waste water heat recovery	16,333	152	£186	1.22
Fix compressed air leaks	6,570	387	£200	0.516
Reduce comp. air pressure	2,816	166	£20	0.12

From building improvements :

Measure	kWh Saveable	£ Saveable	£ Investment	SPBP(Years)
Improve insulation	1467033	27,344	£51,870	1.9
Fit double glazing	168071	3,132	£17,100	5.46
Upgrade control systems	13845	4615	£40,604	8.8

9.1.1.5 Compound Savings and Recommendations

Measure	Benefit	Cost	Pay-back
Reduce room temp to 22°C	£6,300	£30	0.00 yr.
Turn off unnecessary lights	£7,357	£30	0.00 yr.
Close doors and windows	£65,964	£30	0.00 yr.
Cut out electrical heating	£15,963	£30	0.00 yr.
Fit ES fluorescent tubes	£12,026	£30	0.00 yr.
Re-negotiate standing charges	£6,536	£30	0.00 yr.
Reduce lighting levels	£1,324	£30	0.02 yr.
Reduce compressed air pressure	£166	£20	0.12 yr.
Fix compressed air leaks	£387	£200	0.52 yr.
Fit compact fluorescents	£2,111	£1,152	0.55 yr.
Recover heat from waste water	£152	£186	1.22 yr.
Improve roof insulation	£26,126	£51,870	1.99 yr.
Fit double glazing	£2,993	£17,100	5.7 yr.
Upgrade control systems	£4,615	£40,604	8.8 yr.
Re-negotiate tariffs in line with reductions achieved			
Repeat the energy management exercise on an annual basis			

Based on these figures about 56%, £152,020, of the £273,591 energy bill seemed to be saveable. This was more than the initial estimate of £111,185 based on the site's NPI rating, but not excessively so. About 78% of the potential saving was from measures with a pay-back period of less than 3 years, and about 76% was saveable from low cost measures.

9.2 Richmond upon Thames College

9.2.1 Initial Assessment

The New Client module gave the site an NPI rating of 578 which is very poor, and estimated possible low and no cost savings of between £75,050 and £87,643 from the total annual energy bill of £145,567.54, i.e. about 60% of the energy is being wasted and it is financially worth doing something about it.

On this basis EMAN recommended that the full energy management exercise be carried out.

Final Assessment
From site survey, billing information, and meteorological data the EMAN programme gave the following assessment:

U value : 2.135 Base Temperature : 15.01°C

9.2.1.1 Energy Management

Based on the management structure and energy awareness checklist.

Energy Awareness on site is poor.

- Maintenance should be improved.
- Draughtproofing is poor.
- Record keeping is inadequate.
- Responsibilities need to be clarified.

- Staff need training in energy awareness.
- Unnecessary lighting should be turned off.
- Doors and windows should not be left open when the heating is on.
- Staff need to be involved in, and aware of, energy efficiency initiatives.
- Energy related Accounts should be reported to the Energy Manager.
- HVAC operations should be reported to the Energy Manager.
- Lighting and other electrical installations should be reported to the Energy Manager.
- Energy related Maintenance should be reported to the Energy Manager.
- Energy issues related to working practice should be reported to the Energy Manager.
- Service Records should be kept for all Energy Related Plant. For some items, e.g. Boilers, failure to do so may invalidate insurance.

9.2.1.2 Energy Use Breakdown

Fuel	**Percentage of Total kWh**	**Percentage of Total Cost**
Gas	73.49 %	21.5 %
Peak Electricity	21.49 %	71.87 %
Off Peak Electricity	5.02 %	6.63 %

81.7% of the building loss was due to infiltration, corresponding to 8.07 ACH. It was estimated that closing doors and windows would reduce this to 4.95 ACH, and fitting draught-proofing would drop it to the 2 ACH recommended for this type of site.

9.2.1.3 Stand Alone Savings Possible

From improved Energy Awareness :

Measure	kWh Saveable	£ Saveable
Cut out Electrical Heating	630108	30,567
Close Doors and Windows	2607741	13,870
Turn off unused Lights	34344	1,666

From improved Services :

Measure	kWh Saveable	£ Saveable	£ Investment	SPBP (Years)
Replace GLS with compact fluorescent	1790	86.84	144	1.66
Fit 22m ES fluorescent tubes	64464	3,127.24	0	0
Waste water heat recovery	4900	13.03	81.67	6.27
Fix compressed air leaks	320	15.52	80	5.15
Reduce comp. air pressure	640	31.05	20	0.644

From building improvements :

Measure	kWh Saveable	£ Saveable	£ Investment	SPBP (Years)
Improve insulation	201231	1,070	26000	24.3
Fit double glazing	406840	2,164	77760	35.9
Fit draught proofing	2472643	13,152	105680	8.04
Upgrade control systems	32097	10699.13	8236.88	0.77

9.2.1.4 Compound Savings and Recommendations

Measure	Benefit	Cost	Pay-back
Turn off unnecessary lights.	£166	£30	0.02 yr.
Cut out electrical heating	£30,567	£30	0.00 yr.
Close doors and windows	£15,461	£30	0.00 yr.
Fit ES fluorescent tubes	£2,814	£30	0.01 yr.
Reduce compressed air pressure	£31	£20	0.64 yr.
Upgrade control systems	£10,699	£8,237	0.77 yr.
Fit compact fluorescents	£78	£144	1.84 yr.
Fix compressed air leaks	£15.52	£80	5.15 yr.
Recover heat from waste water	£13.03	£82	6.27 yr.
Fit Draught-proofing	£14,660	£105,680	7.21 yr.
Improve roof insulation	£1,193	£26,000	21.79 yr.
Fit double glazing	£2,412	£77,760	32.24 yr.
Re-negotiate tariffs in line with reductions achieved			
Repeat the energy management exercise on an annual basis			

In practice those measures with a pay-back period greater than 3 or 4 years are unlikely to be carried out except as part of some other undertaking such as refurbishment of the building. In this case it can be seen that nearly 80% of the energy cost saving is from measures with a pay-back period of less than 3 years. It can also be seen that about 63% of the £78,100 saveable is from low cost measures[1] (a nominal cost of £30 has been allocated for administration of so called no cost measures). This is within the range of the initial estimate of £75,050 to £87,643 based on the site's NPI rating.

The potential saving was more than the average of 30% which ETSU give as the typical improvement from low cost measures, but the site was badly mismanaged with no

[1] On this site there is a hidden low cost measure disguised as a major investment because upgrading the controls would simply require re-instatement of the existing system and not a major installation. The computer was not aware of this and estimated the cost of upgrading to a new control system.

attempt at saving energy, and the findings of the programme fit in with the estimates made by the survey team when assessing the site.

9.2.1.5 Feed back from the college

Peter White expressed interest in the survey, and as a result the Landis and Gyr control system was reinstated. The college also managed to get the windows refurbished and double glazed under the "Hunters" scheme, even though this was not the most cost effective improvement they could have made government money was available specifically for double glazing and they wouldn't have got it for any other improvements.

10. Discussion

10.1 Operation Of The System

The energy management programme is an effective tool for the assessment of energy wastage in buildings. The EMAN software is designed to assist a human energy manager by providing a structure for them to conduct an assessment of the energy use on a wide variety of sites. Routine energy management tasks are automated and structured in a user friendly manner to reduce the effort required by skilled personnel. The programme is structured around a series 28 of linked dynamic database tables connected by sophisticated families of subroutines which are designed to automatically collate, process and report key data.

The database tables undertake several roles within the programme. The first family of tables collates and stores site specific information such as administrative details, location, energy usage, costs, building structure, heating services, lighting types and water usage. A second family of table provides stored libraries of information such as typical energy characteristics of various types of site, construction details and thermal properties of building components, fuel characteristics, typical boiler efficiencies, meteorological data and geographical data suitable for use in the mapping of the site in relation to meteorological stations. The third and final type of table is used for the collation and storage of the results of the analysis performed by the EMAN programme.

During testing the following points were noted and should be addressed by future researchers:

10.1.1 Rogue Data Points

The energy signature model is highly sensitive to poor quality data, and is not therefore foolproof. If necessary, it may be possible to address this issue through the development of automatic filters which check the validity of data and discriminate rogue points from acceptable ones. Alternatively, it may be appropriate to develop a programme or sub-routine which allows the human energy manager to reject points on the energy signature graphs which appear erroneous on the basis of his or her experience.

10.1.2 Electrical Correlation

There is some disagreement within the energy management industry with respect to the validity of correlating electrical energy input against external air temperature to identify electrical heating and base loads. It is considered possible that the suitability of such correlations might vary between different types of site and that this approach may therefore warrant further research.

10.1.3 Availability of Data

Clearly the accuracy of the analysis undertaken by EMAN is dependent on the quality of the available data. Under optimal conditions it is anticipated that the programme would give similar predictions to those of an experienced human energy manager, but with a much lower expenditure of effort. It has been found, however, that poorly managed sites are typically unable to provide sufficient data on their energy use to generate the building energy signature. As a result of the iterative nature of energy management, such deficiencies can be overcome. Inadequate data can be highlighted during the first site audit and remedied through the implementation of energy accounting procedures designed to provide accumulate the necessary information for use in a subsequent audit.

10.1.4 Changes To The Electrical Tariff System

Since the EMAN programme was written, changes have been introduced to the energy supply industry to promote the development of a free market. As a result of these changes, most customers no longer use Maximum Demand based electricity tariffs and instead have moved to variable charge based tariffs. The Maximum Demand section of the programme is therefore now largely redundant. Variable charges could still be accommodated by averaging the peak and off-peak costs over the year to give one peak unit charge and one off-peak unit charge.

10.2 Suggestions For Further Work

10.2.1 Beta Testing

The prototype EMAN programme has successfully completed an initial (alpha) testing programme based upon limited site data. Prior to its adoption as a working product, the software will require further testing and fine tuning through the use of reliable and accurate data from a number of sites.

10.2.2 Programme Refinements

It is the nature of software development that as long as there is a need for a product then development is open ended and that and that additional functionality will always be sought. It is anticipated that the EMAN programme will undergo a process of continuous evolution since the areas into which it can be developed in the energy, environmental and management fields are vast. Several areas of the programme as it currently stands suggest potential for improvement in the short term. These areas are as follows:

- Creation and integration of a tariff analysis sub-module.
- Development of user updatable INI files to store programme default information.
- Recompilation as a 32 bit programme to take advantage of the full range of functionality available under Windows 98 and Windows NT.
- Development and incorporation of routines to identify and discriminate between valid data and rogue data.
- Development and incorporation of an integrated reporting module to replace the Borland ReportSmith report generator supplied with Delphi, which is large and clumsy, sometimes locking database table and crashing the programme. It would be better to develop a simpler report generator within the energy management programme dedicated to the task of printing out the programmes recommendations.

The functionality and usefulness of the programme could be optimised throughout its lifespan through an ongoing process of updating and expansion of the library databases as additional information becomes available.

10.2.3 Lighting Estimator

A lighting estimator which could analyse the existing lighting against user requirements, and then suggest a more effective lighting design for the building requires too much detailed information to fit into the energy management programme. In effect each room would have to be considered in detail, including activities, dimensions, aesthetic preferences, furnishing and finishes, etc.

It would, however, make a useful computer based tool in its' own right

10.2.4 Pay To Use

Growth of the Internet and other dial up services is making it both technically possible and commercially acceptable to sell end users access to software, rather than the software itself.

It is anticipated that a suite of energy management tools made available over the Internet on a relatively low cost pay-as-you-use basis would be more attractive to many potential users than a stand alone package. There are a number of reasons for this.

- The risk to the purchaser is low, for little financial outlay he or she can try out the package to see if it does what is required.
- The purchaser would only pay for the tools needed.
- Use of the service could be directly costed against a job.
- The cost should be relatively low because there would be no manufacturing and little distribution cost associated with marketing the product. The cost to the producer would be in developing and maintaining the energy management software and website, and any promotional/advertising costs.
- Information in the databases used by the software tools could be constantly updated, and improved versions of the software downloaded, so the end user is not with software that is only a year old but obsolete.

- Meteorological data could be accessed over the web (at commercial rates), rather than by post.

Borland provide Internet development tools which work with Delphi, but such development would be outside of the scope of the current work.

This approach could be used for computer based training courses. As new course materials were developed they could easily be added to or replace the existing materials. People could either work live on line, or download parts of the course, in either case payment could be made by credit card like most other pay-to-access services on the Internet.

Another viable alternative would be a straight dial-up service via the telephone, like that provided by the environmental consultancy Entec's Eonline. This is self-contained rather than using the Internet, which may be cheaper to run but means that users might have to pay higher phone charges for non-local calls.

10.2.5 Computer Based Training

The introduction of the National Standards for Managing Energy and the associated NVQs allow scope for the development of educational and training support materials.

Much of the energy management programme could be taken as the core for a computer based training system for energy management.

11. Conclusions

The work was conducted with the aim of producing an expert system to carry out routine energy management tasks by employing building energy signatures and sparse data analysis.

The work was successful in this aim, and the resulting software prototype, EMAN, provides a highly automated energy management tool suitable for use by professional energy managers. EMAN utilises a number of novel approaches including the construction of location specific weather data from sparse data, intensive background calculations, automatic energy auditing and automatic generation of recommendations for fast pay-back low-cost energy saving measures on the basis of minimal data input.

This is accomplished by providing a number of background databases containing technical data for, for example, the u values of building components, meteorological data, site type characteristics, etc. Thus when the user inputs the location of a site the monthly external air temperatures at the site are automatically calculated. This together with geometrical dimensions and selected constructional details of the building components allows the background mathematics to automatically calculate the overall U value for the building, the number of air changes per hour and the ratio of sundry gains to building heat load. This leads to the full construction of the balanced energy audit, which is automatically examined by the software to identify and evaluate low cost fast pay-back energy saving options applicable at the site.

The software is modular in design and includes sub-programmes for the following:

- New client acquisition and preliminary assessment.
- Site surveying and auditing.
- Logging of monthly energy use.
- Derivation of site specific meteorological information.
- Correlation of energy usage with meteorological information.
- Development of the energy signature for the site.
- Construction of the energy balance for the site.
- Quantification of the potential for individual low cost energy saving measures.
- Development of an optimised investment plan for the site.

A number of potential avenues of future research and development were highlighted in the course of the work and are discussed in detail elsewhere within this document.

The performance of the expert system was tested by use of a synthetic data set based on sites audited in the course of research associated with the work. The programme was then further tested using data collected from a large tertiary college site. The results of the testing programme indicated that the software produced credible predictions which were in line with those made by experienced energy management professionals.

12. GLOSSARY

Artificial Intelligence	"The science of making machines do things which would require intelligence if they were done by a human"- Marvin Minsky
Ballast	Electrical or electronic device to initiate and sustain a discharge, used in various types of lighting.
Calorifier	Hot water generator employing a heating coil from the main space-heating circuit, like a large domestic central heating hot water tank.
Clean coal	Technologies employing high efficiency combustion, exhaust scrubbers, etc., to reduce the pollutant effects of coal burning.
Combined cycle	Use of a gas turbine, diesel engine, etc., to generate power, and then using the waste heat from that primary to drive a secondary steam turbine which can also generate power.
Control Band	Generalised description of the level of sophistication of a control system, as described in current Building Regulations.
Curie	Unit of radioactivity equal to 1 gram of Radium 226
Desertification	Aridification and reduced biological productivity of land.
Destratifiers	Usually fans or ducted air units used to counteract stratification and re-circulate warm air.
Diurnal	Daily, of the day.
Expert System	Computer system designed to mimic a human expert
Fuzzy logic	Use of shades of grey rather than Black or White arguments. E.g. using multiple reference points and weighted averages to gain an approximation of the value at a point rather than simply using the value of the nearest reference point.
Green	Environmentally friendly.
Inference Engine	A sub-programme which co-ordinates data access and processing in a knowledge based system
Knowledge Based System, (KBS)	A computer system which attempts to emulate human knowledge or expertise
Legionella	Bacterium causing Legionnaires disease
Lossy compression	Data compression for applications where exact reproduction is unnecessary. Data integrity is traded for a higher compression.
Luminaire	Light fitting (*in which the lamp is housed*)
Oktas	Eighths of the sky, used as an estimate of cloud cover
Photovoltaics	Devices, usually semiconductors, which convert incident light energy into electrical energy.
Renewables	Energy resources which are naturally generated at a rate which makes them effectively inexhaustible.
Smog	Originally coined in 1905 to describe a combination of smoke and fog, now taken to mean any smoky or hazy

	pollution. The original London smog was characterised by sulphur oxides and particulates from coal fires. Los Angeles, or photochemical smog is characterised by NOx, ozone, and peroxyacetyl nitrate resulting from the action of sunlight on NOx and hydrocarbons in the atmosphere.
Stratification	Temperature gradients from floor to roof level due to the natural tendency of warm air to convect upwards.
Therms	Units in which gas is often sold. 1 therm = 29.31 kWh
Troposphere	Lower atmosphere, up to about 17,000 metres.
Working Temperature	The mean external air temperature during the hours of operation of the building heating system

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13.7 Also Occasionally Useful

Science Line: telephone 0345 600 444

Appendix A

Pro Forma Questionnaires

Appendix A: Pro Forma Questionnaires

New Client Questionnaire

Client Site Details

Company	*Contact*
Site	*Phone*
Street	
Town	*Post Code*

Auditor:	
Site Type	
Floor Area	
Occupancy (Hours/Year)	
Exposure:	

Site Energy Use

Annual Energy Cost, £:
Billing Year:
Degree Days:

Primary Heating Fuel		*Consumption*	
Secondary Heating Fuel		*Consumption:*	
% of Fuel used for DHW		*Non Heating Electricity kWh*	

Site Survey Questionnaire

Management Structure

	Responsible	*Phone*	*Reports to*
Energy			
Accounts			
HVAC			
Electrical			
Maintenance			
Shop Floor			

Comments:

Notes

Energy Awareness Checklist

Lights turned off	***Adequate records***	***Adequate Insulation***
Doors and windows closed	***Clear responsibilities***	***Draught proofing***
Staff Involvement in energy saving	***Skilled operators***	***Good Maintenance***

Staffing Levels

Clerical:	***Manual:***

Comments:

Structural

Areas

Plan Area, m^2		*Floor Area, m^2*	
Length of North Elevation, m		*Length of West Elevation, m*	
Wall Height, m			
North % Glazing		*East % Glazing*	
South % Glazing		*West % Glazing*	
Area Doors type 1, m^2		*Area Doors type 2, m^2*	

Construction

	Construction	*u value (if known)*
Walls		
Windows		
Doors 1		
Doors 2		
Roof		
Floor		

Heading

Space and Water Heating

	Heater Type	*Effy.*	*Last Serviced*	*Last Failed*
Primary				
Secondary				
DHW				

Controls

Internal Temperature, °C:	*Hot Water Temperature, °C:*

Start Time:	*Finish Time:*	*Control Band level:*

Lighting

	Installed Wattage	*Utilisation, Hours/year*
GLS		
GLS Spotlights		
38 mm Fluorescent Tubes		
MBFU Floodlighting		

Maintenance

Cleaning & Maintenance period:	*Fluorescent Replacement period:*

Wastage

% Lights left on when not needed:	*% Excess Lighting installed:*

Services

Compressed Air

Compressor Power, kW:	*Utilisation, Hours/year:*
Set Pressure, bar:	*Usable Pressure, bar:*
% Leakage Loss:	

Water

Annual Water Usage, Litres:	
Supply Temperature, °C:	*Drain Temperature, °C:*

Other Quantifiable Gains and Losses

OQ Gain, Annual kWh:	*Cause:*
OQ Loss, Annual kWh	*Cause:*

Energy Consumption Questionnaire

Meteo

Client Site National Grid Co-ordinates:			

Unit Costs

Fuel Tariffs

Primary Heating Fuel unit cost:
Secondary Heating Fuel unit cost:

Electricity Tariffs

Standard Rate £/kWh:
Cheap Rate £/kWh:
Supply Capacity Charge, £/kVA:

Supply Levels

Step 2 Level, kVA:
Supply Capacity, kVA:

13.7.1 Fuel Use

Month	*Days worked*	*Primary Fuel used*	*Secondary Fuel used*
Jan			
Feb			
Mar			
Apr			
May			
Jun			
Jul			
Aug			
Sep			
Oct			
Nov			
Dec			

13.7.2 Electricity Use

Month	*Consumption levels*		*MD Charges, £/kVA*		
	Standard	*Off Peak*	*MD kVA*	*Step 1*	*Step 2*
Jan					
Feb					
Mar					
Apr					
May					
Jun					
Jul					
Aug					
Sep					
Oct					
Nov					
Dec					

Appendix B

Boiler Efficiency Data from BS 845

Appendix B: Boiler efficiencies

Typical control errors (from BS 845, Methods for the assessing the thermal performance of boilers, Part 2)

Parameter	Accuracy ±
Atmospheric pressure	0.5 %
Gas pressure	0.5 %
Steam pressure	1 %
Mass of water or fuel	0.2 %
Flow rate of water or fuel	0.5 %
Flow rate of steam	0.5 %
Time	0.1 %
Calorific value	0.6 %
Gas temperature	1°C
Water temperature	0.1°C
Carbon monoxide in flue gas	10 %
Oxygen and Carbon Dioxide concentrations	0.2 %

Typical radiative, conductive, and convective losses

Water tube and Shell boilers;-

Type	Design	Total loss at rated output
A	Water tube and multishell boilers >5 MW	0.3 %
B	" 2 < 5 MW	0.5 %
C	" < 2 MW	1 %
D	Brickset & dryback multitubular & brickhearth boilers	1.5 %
E	Brickset water tube boilers with water walls	2 %
F	" without water walls	2.5 %
G	Brickset Lancashire and Cornish boilers	4 %

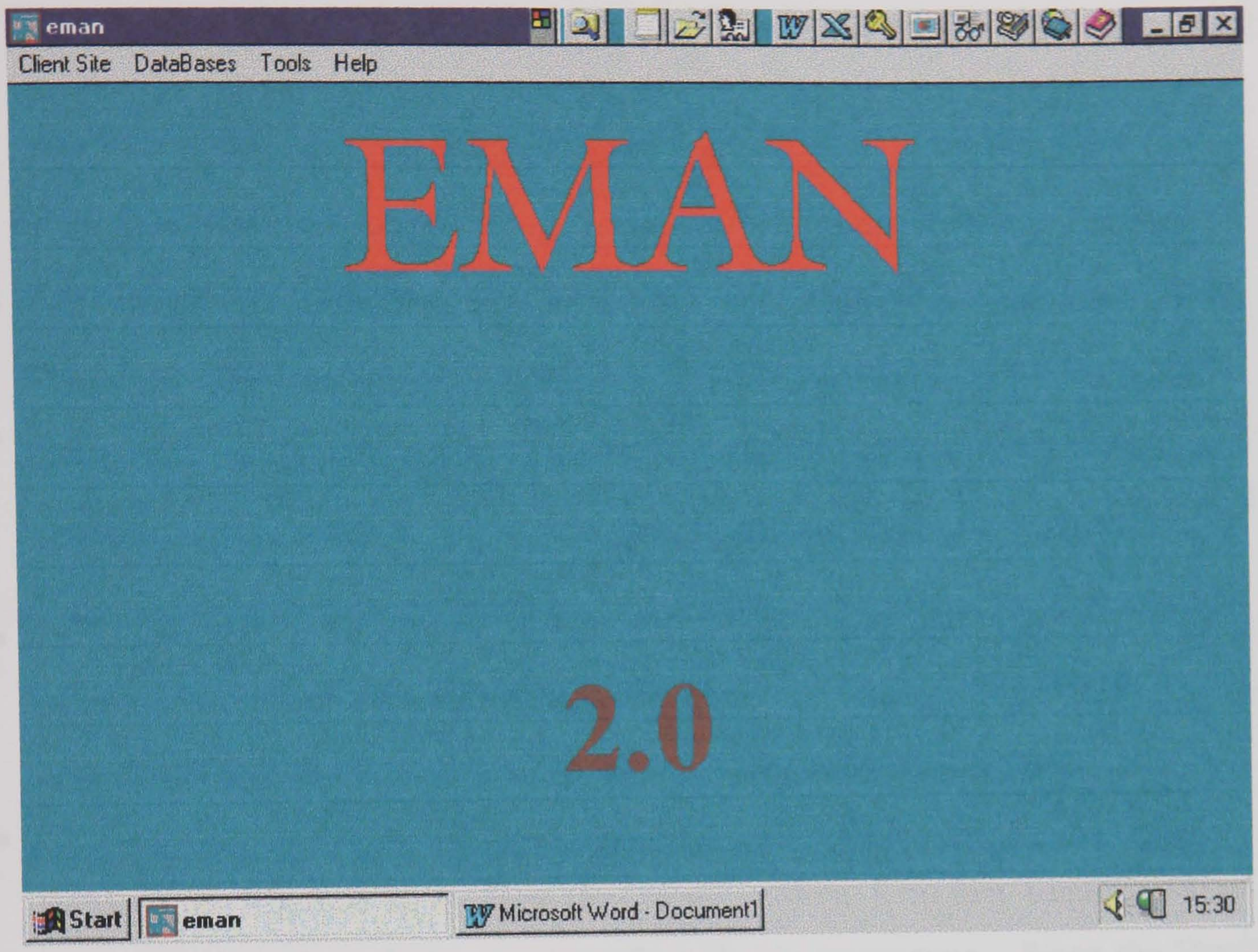
Sectional Hot water boilers

Type	Direct openings from Combustion Chamber	Water cooled base	Non water-backed surfaces	Insulation	% Loss
A	None	Yes	< 10 %	40mm on boiler surface	1.5
B	< 2000m²/kW	No, but <120°C	< 10 %	"	3
C	"	no, <9000 mm²/kW	< 10 %	25 mm within casing	4

ANNEXE

Using the EMAN Energy Management Programme

Using the EMAN Energy Management Programme



Contents

1. Installation.

- .The EMAN programme will require 16.4 Megabytes of free disc space. The Borland Database Engine must also be installed, This requires an additional 3.2 Megabytes of free disc space.
- Copy the directories and files from the programme diskettes or CD Rom onto the C drive of an IBM compatible PC running Microsoft Windows
- Copy the ChartFX.VBX and Bivbx11.DLL files into the Windows \ System directory of the computer.
- Install the Borland Database Engine from the 2 Bdeinst discs. Use the BDE Configuration utility supplied with the BDE to create aliases "EMAN" and "NPIBase". Set the alias paths to C:\lnprogs.
- The BDE Configuration utility can also be used for creating or modifying aliases and paths if later developers add directories or change existing directories containing programme databases.
- If you wish to use ReportSmith for displaying, editing, or printing install the ReportSmith Runtime utility from the 5 Rptinst discs. This may cause problems as ReportSmith tends to lock records and crash the programme. Since the Paradox format database tables used by the EMAN programme are ODBC compliant the information can be directly imported into most standard office applications such as spreadsheets, databases, and some word processors, without using ReportSmith.
- If there is a problem installing and running the programme, the source code can be recompiled on any PC using a copy of Borland Delphi 1. A PC with Delphi correctly installed would already have the ChartFX.VBX and Bivbx11.DLL files and BDE correctly installed, though the database alias would still have to be configured.
- Delphi 1 is now given away free with Delphi 2, and has also been made freely available for educational but not commercial use. In December 1998 Inprise/Borland were selling Delphi 2 for £49 + VAT[1]
- If problems are encountered during installation or operation please call Liam Nagle on (0181) 892-2403.

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[1] Order by Phone: 0800 454065, Fax: 0800 454066, Post: Inprise (UK) Ltd., Freepost RG1571, Twyford, Reading, Berks, RG10 8BR.

2. Recompiling the Source Code.

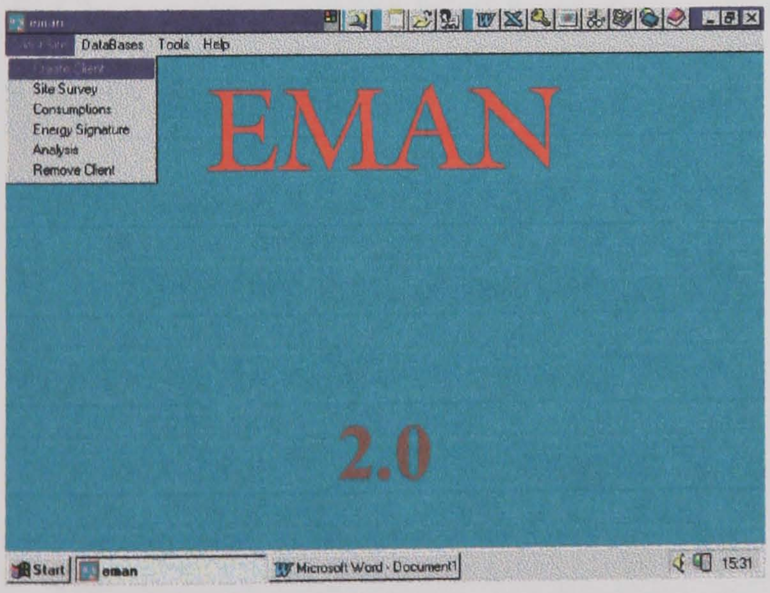
- The original Delphi 1, 16 bit Windows 3.x, source code is provided as a basis for future developers to work from.
- Delphi 2 for 32 bit Windows 95 and NT development includes Delphi 1 for 16 bit Windows 3.1 development. Later versions of Delphi may not be able to compile 16 bit code, and some modifications to the programme may become necessary if the Delphi Visual Components are changed. These changes should be supported by the Borland Delphi Help files of the version used. The Borland Delphi 2 CD Rom gives guidance for converting Windows 3.1 to Windows 95 and NT programmes under "Migrating 16 Bit Delphi Code" and D32_Note.Doc in the Info\Borland directory.

3. Running the programme

- Running EMAN2.EXE in the C:\LNPROGS directory will start the EMAN Energy Management programme and display the Main Screen. The programme was written for 640 x 480 screen resolution, and may appear different at other screen resolutions.
- Use the pull down menus in the title bar to access the programme modules.

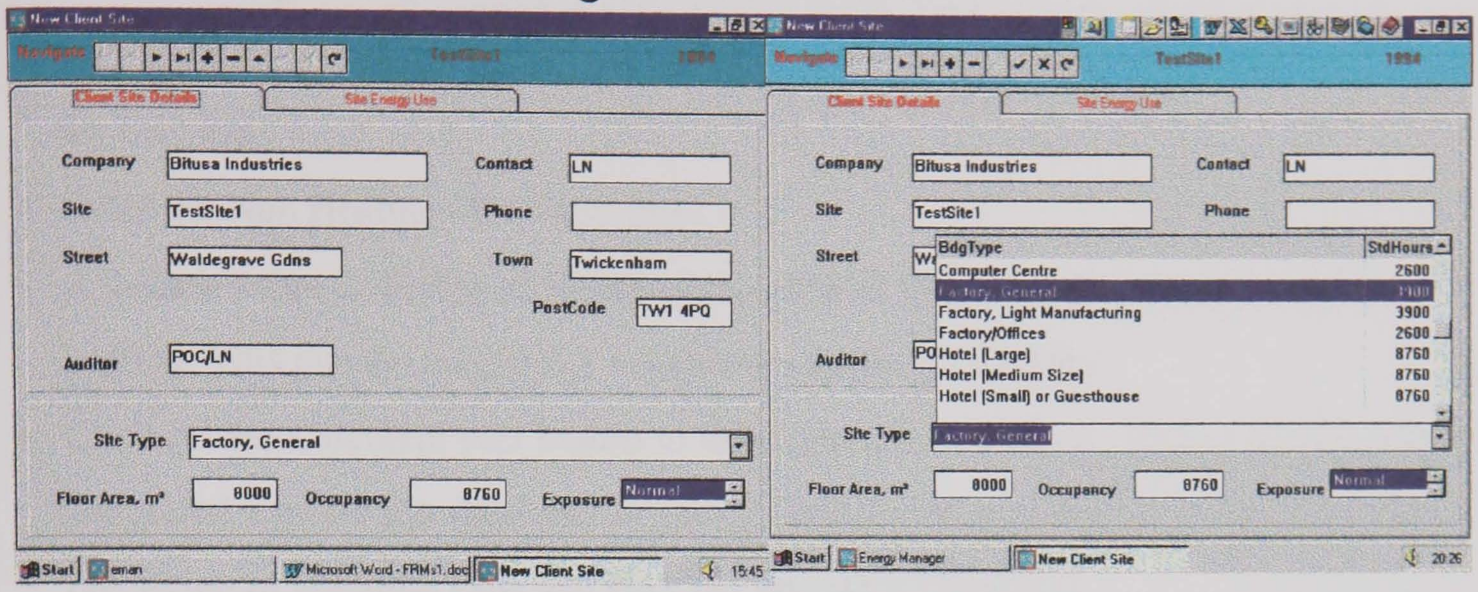
4. Creating a New Client

4.1 The Main Screen



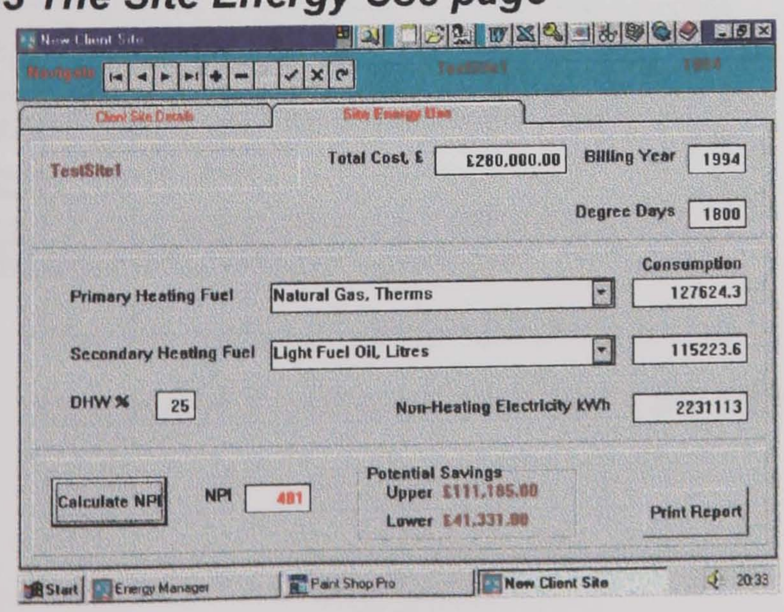
- Click on Client Site in the Main Screen toolbar to display the Client Site Menu.
- Click on Create Client to start the New Client Site module.

4.2 The Client Site Details Page



- Create a New Client record by clicking "+" in the Navigator button bar. To edit an existing record use the arrow buttons to locate the record in the database.
- Enter the administrative details in the Client Site Details page.
- Pull down the Site Type from the Site Types database by clicking on the button in the Site Type box and choosing the appropriate type.
- Enter the Floor Area in square metres.
- A default value for Annual Occupancy Hours will be displayed, based upon typical occupancy for that type of site. This may be edited if the Client Site occupancy is different from the default.
- Choose the exposure level from the scrollable box.
- Click on the Site Energy Use tab to turn the page.

4.3 The Site Energy Use page



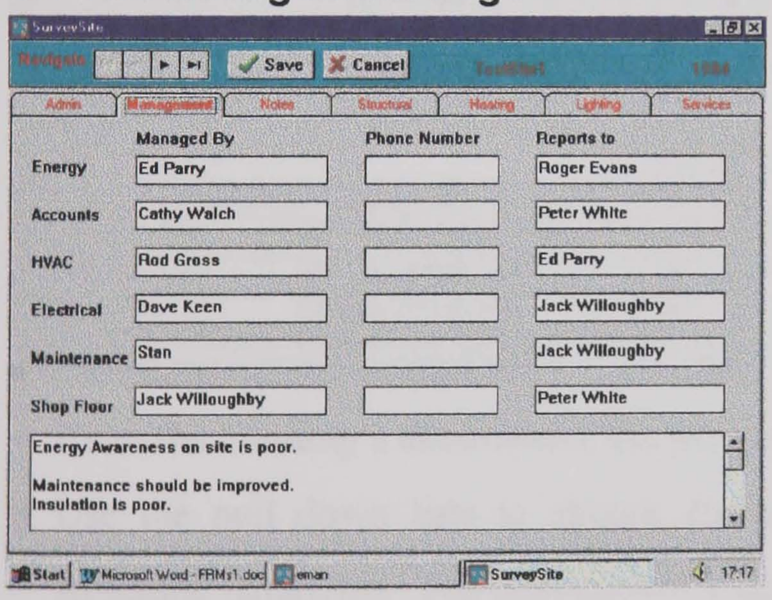
- Enter the Total Annual Energy Cost and the relevant Billing Year.

- Enter the Degree Days for the Site for that Billing Year.
- Pull down the Heating Fuel (s) from the database, and enter the number of units used for the year.
- Enter the Non Heating electrical input.
- A default value is displayed for the percentage of total heating energy used for water heating. This may be edited if it is incorrect for the Client Site
- Click on the Calculate NPI button to calculate the NPI value. This is automatically compared against the database to see if further investigation is worthwhile, and a prediction of potential Low and No Cost savings is displayed.
- Click on "✓" in the Navigator button bar to Save the Client Record.
- A preliminary report can be created from the Client Record if the ReportSmith report generator is installed. The record can also be accessed by ODBC compliant word processor, spreadsheet, and database packages.

5. Surveying a Client Site

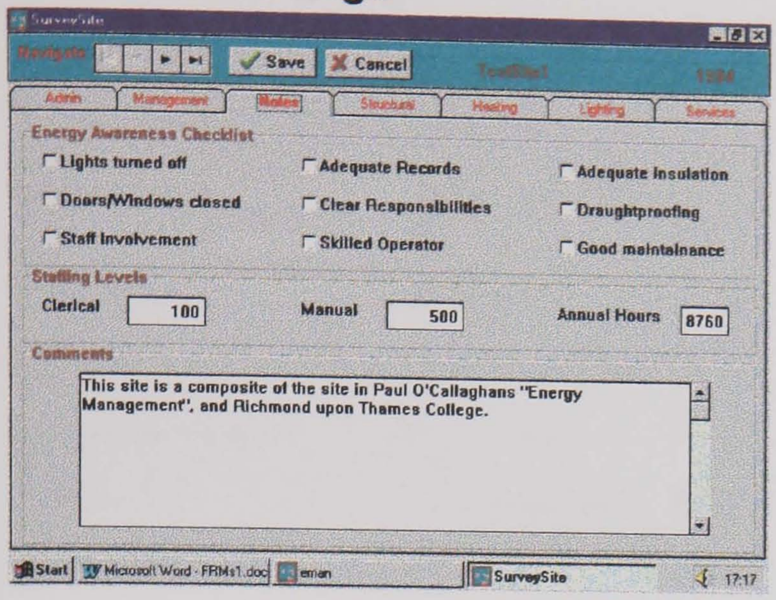
Click on Site Survey on the Main Screen drop down menu.

5.1 The Management Page



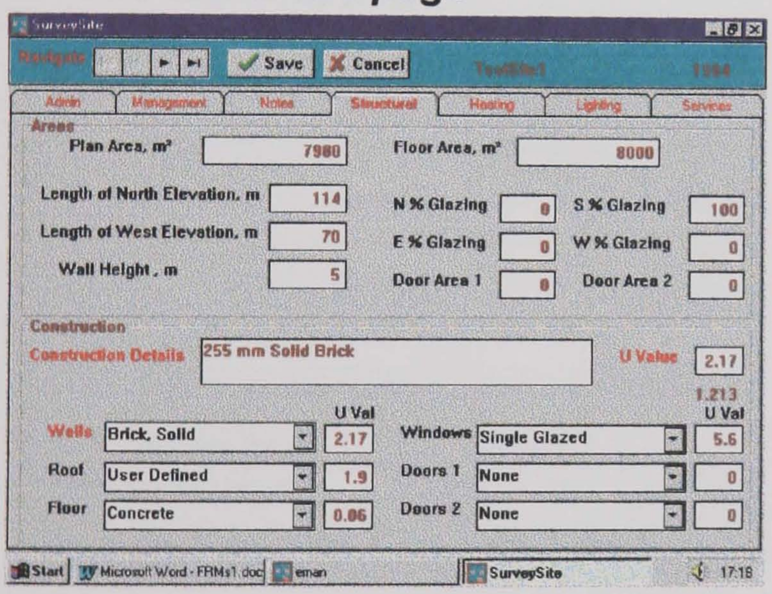
- Enter the details of staff responsible for energy on the Management page. Failures in management structure will automatically be listed in the scroll box.

5.2 The Notes Page



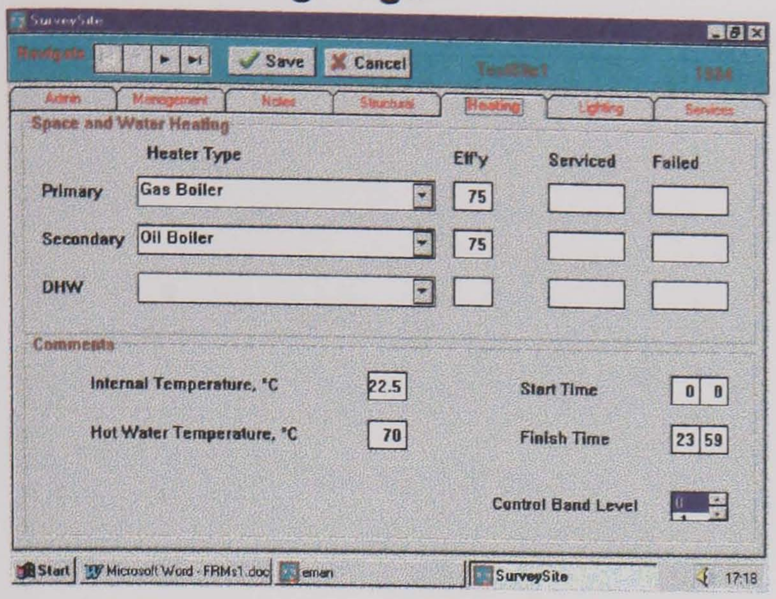
- Tick boxes in the Energy Awareness Checklist, this will generate comments in the Management Page scroll box.
- Enter the number of Clerical and Manual staff on the site.
- Observations made while surveying the site may be recorded in the Comments box.

5.3 The Structural page



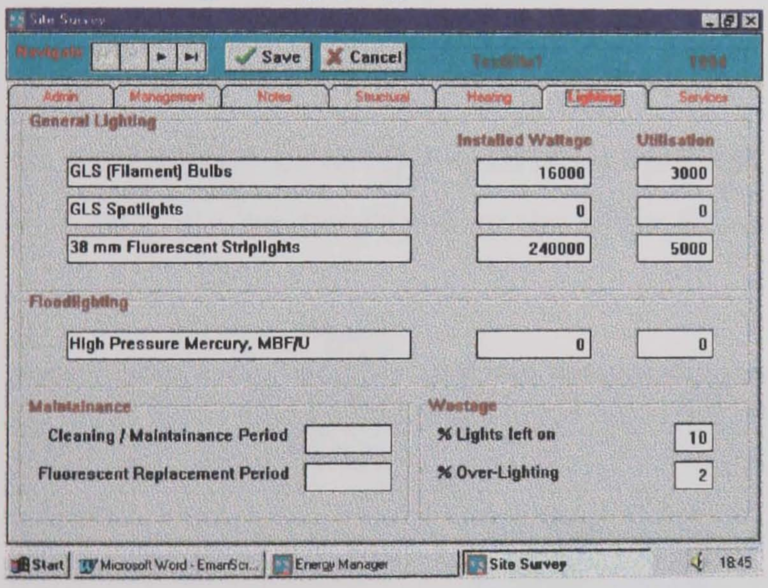
- Enter the building's dimensions, the percentage of glazing, and the areas of doors.
- Use the pull down lists to choose the appropriate Construction Types from the structural databases. The construction details will be displayed when a Construction Type is selected from a list. The Building's U value will automatically be calculated. If the construction is not already listed it can added to the database, or simply given as "User Defined" with it's u value.

5.4 The Heating Page



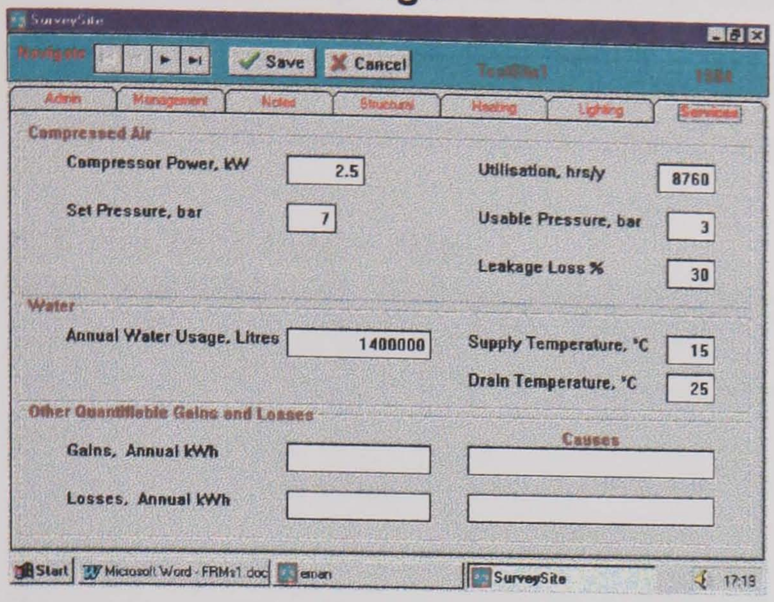
- Choosing the Heater Types from the database gives a default value for the efficiency.
- Enter the Heater Efficiency if known.
- Enter the set temperatures and start and stop times of the heating system.
- Choose the Control Band Level from the scroll box.

5.5 The Lighting page



- Log the estimated Installed Wattage and Annual Hours Of Utilisation for the common low efficiency lighting types.
- Record the Planned Maintenance and Replacement hours.
- Estimate the percentage of lights left on unnecessarily, and the degree of over-lighting.

5.6 The Services Page



- Enter the Compressed Air compressor power, annual hours of use, and set pressure.
- Estimate the required pressure from the equipment installed.
- Estimate the Leakage Loss from the compressor on/off cycling under no load.
- Enter any other Known Gains or Losses.

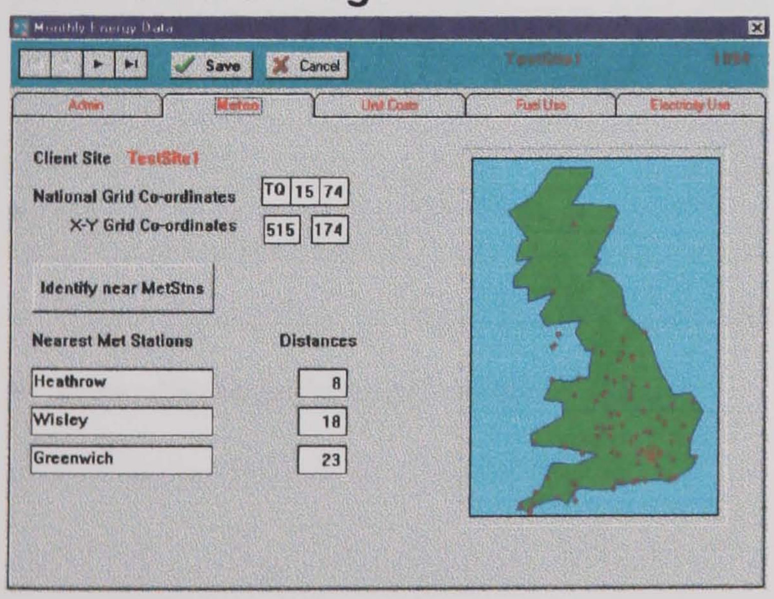
5.7 Saving

- Click on the Save button to post the client site information to the database.

6. Logging Energy Consumption

- Click on Consumptions on the Main Screen drop down menu.

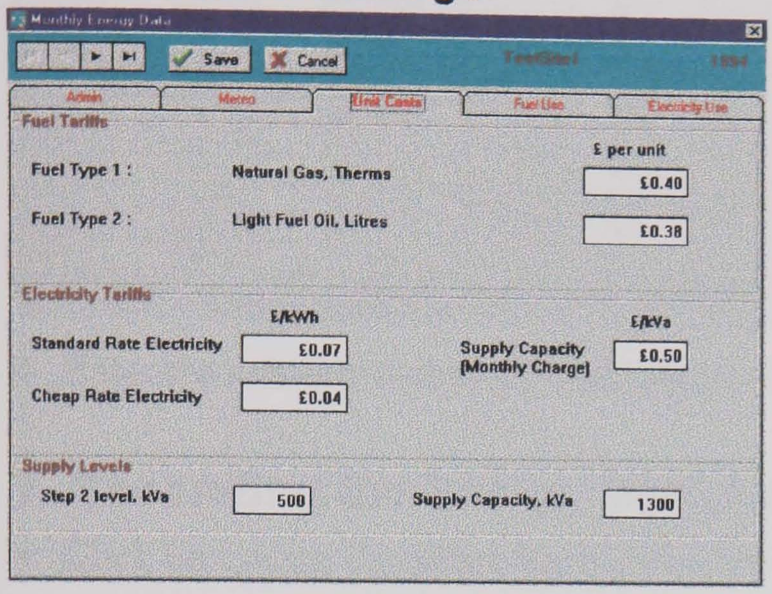
6.1 The Meteo Page



- Enter the National Grid Reference of the Client Site and click on the Identify near MetStns button to identify the three nearest meteorological stations.

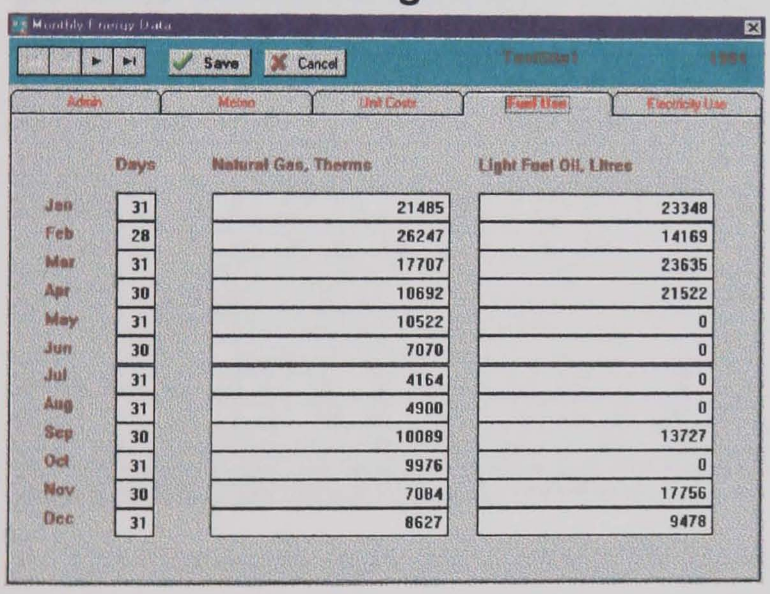
- If it is not already on the database, the weather data for these stations and the year in question must be input using the DataBase/MetData editor from the Main Screen menu. This information can be taken from Met Office 'M' data sheets.

6.2 The Unit Costs Page



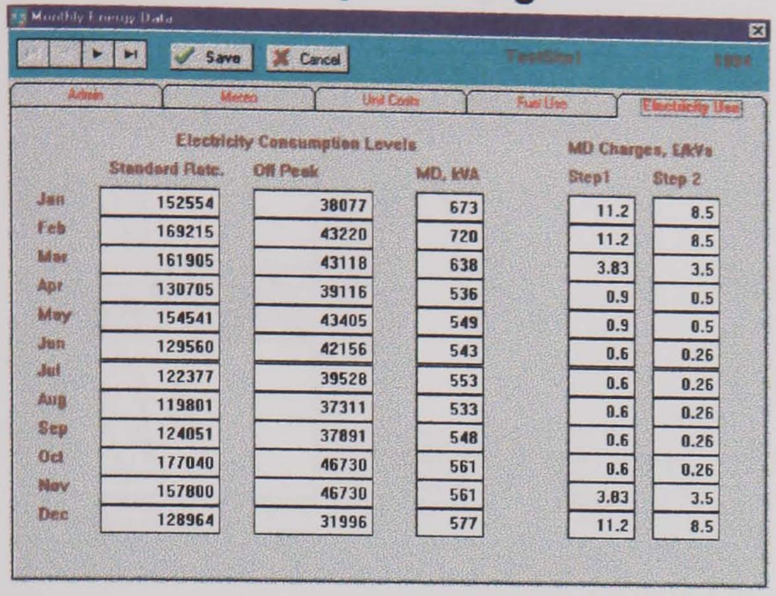
- Record the Fuel and Electricity tariffs.

6.3 The Fuel Use Page



- Enter the number of days worked each month.
- Enter the monthly fuel consumptions.

6.4 The Electricity Use Page

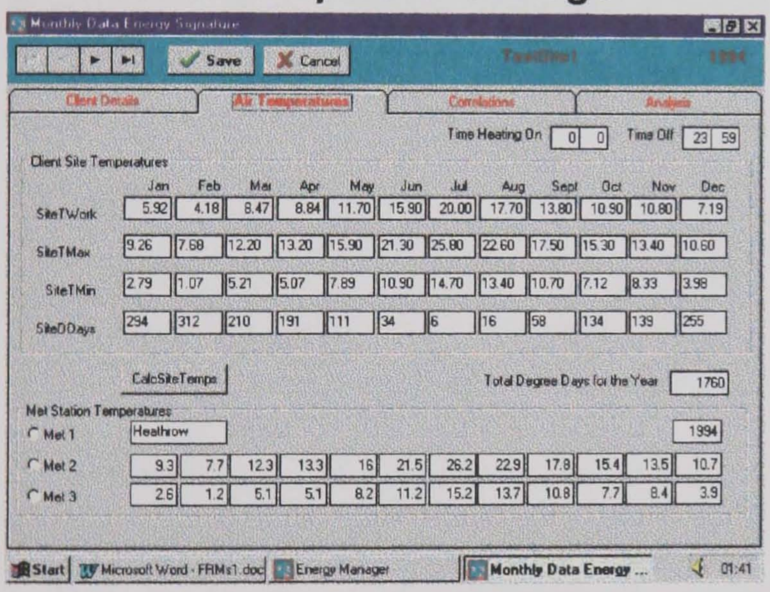


- Enter the monthly electricity consumption levels and maximum demand charges.

7. Generating the Energy Signature

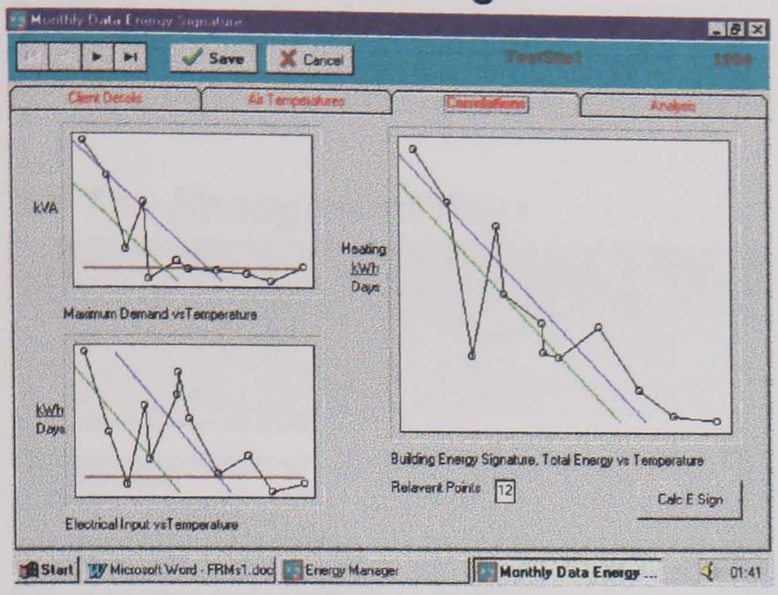
- Click on Energy Signature on the Main Screen drop down menu.

7.1 The Air Temperatures Page



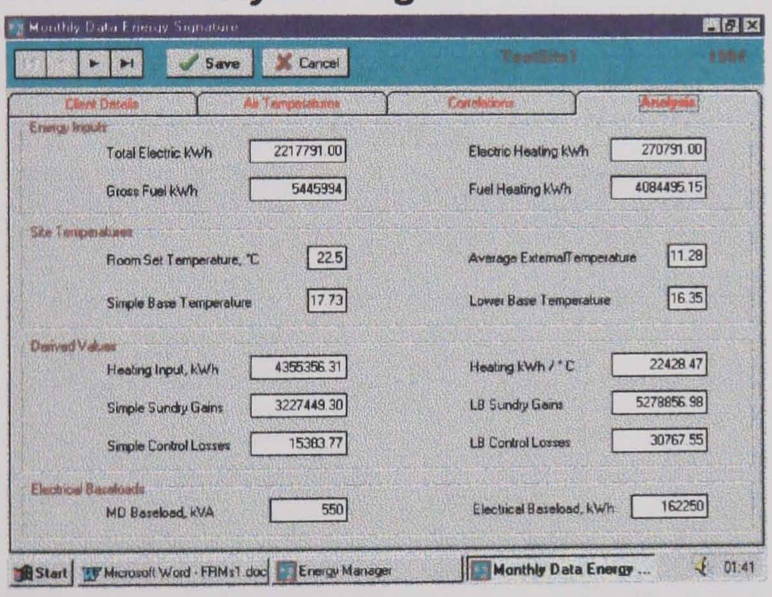
- The maximum and minimum temperatures for the Client Site are automatically estimated based on data from the three nearest meteorological stations.
- The working air temperature is automatically calculated from the maximum and minimum temperatures, geographical position, and month. Degree Days for cross referencing are automatically calculated using the British Gas Method.
- The original data from the three meteorological stations can be viewed.

7.2 The Correlations Page



- The calculated site temperatures are automatically correlated against electrical maximum demand, electrical input, and total energy input to give Building Energy Signatures.

7.3 The Analysis Page

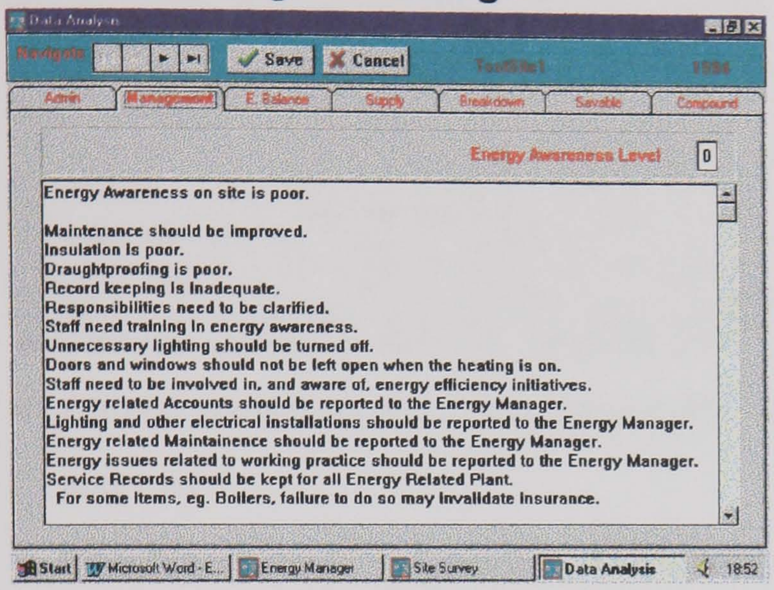


- Base loads, climate dependant loads, the Base Temperature, Sundry Gains, and Control Losses are automatically calculated

8. Data Analysis

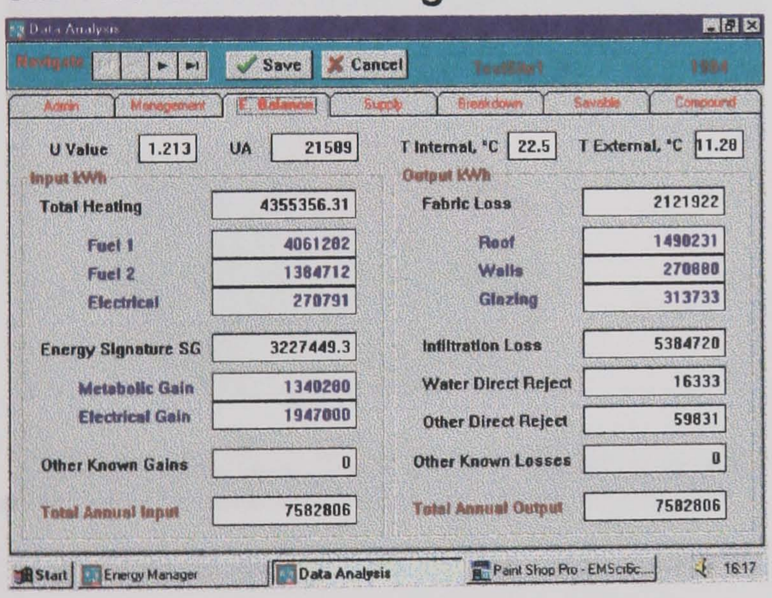
- Click on Data Analysis on the Main Screen drop down menu.

8.1 The Management Page



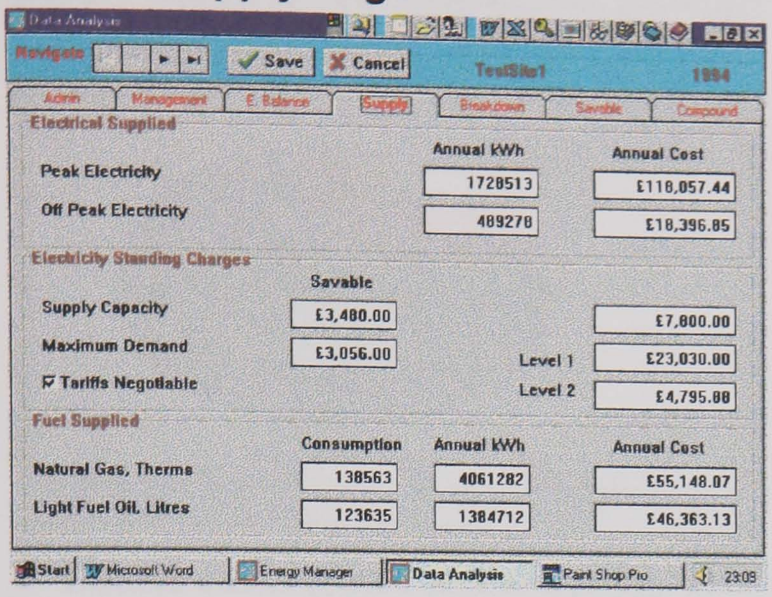
- Management structure and record keeping recommendations are automatically generated.

8.2 The E.Balance Page



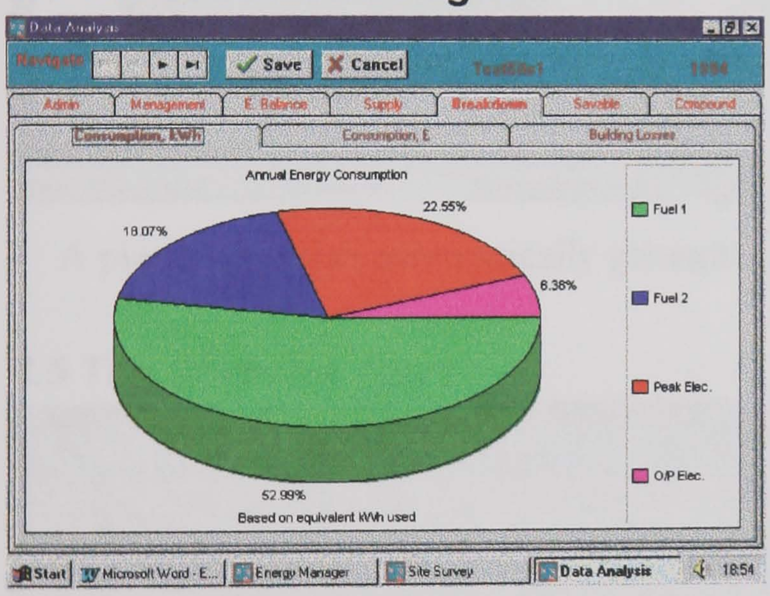
- An energy balance of the major gains and losses is automatically generated
- The main gains and losses are shown in black. Components of the main gains and losses are shown in blue.

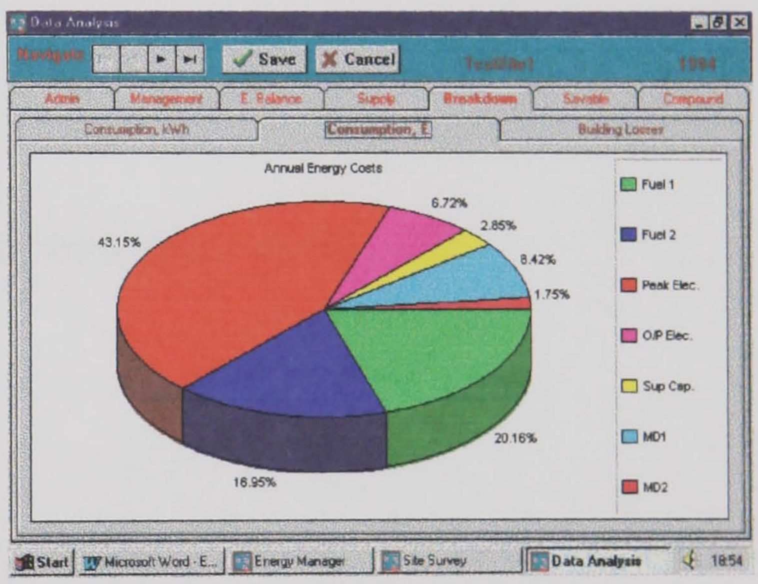
8.3 The Supply Page



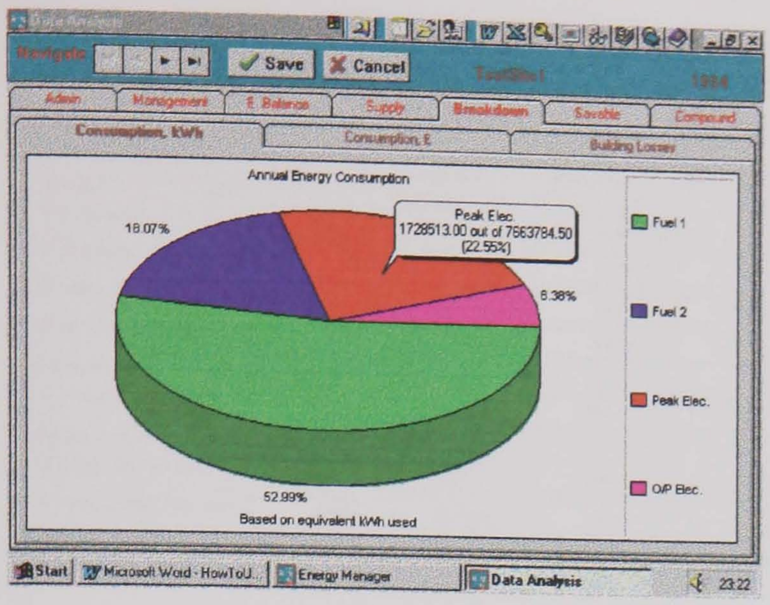
- Annual energy supplied is automatically broken down in terms of Kilowatt - Hours and cost.
- Possible savings from reducing electrical supply capacity are identified. A tick box can be checked if these can be reduced to a lower level under the supply contract.

8.4 The Breakdown Pages

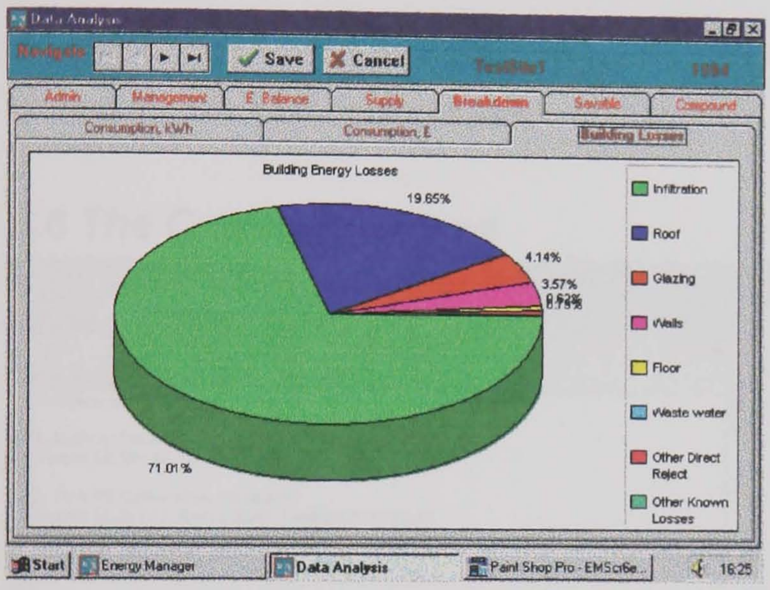




- Pie charts are automatically generated showing breakdowns of kWh and financial costs.

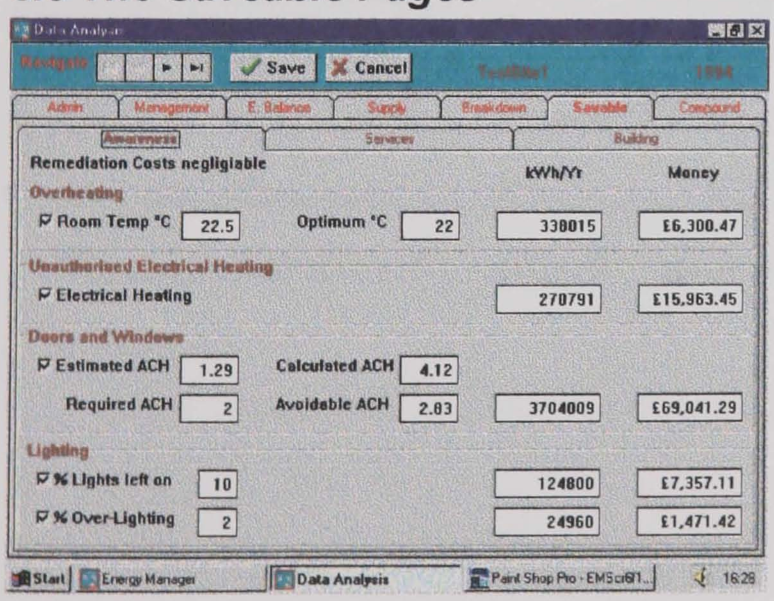


- Double clicking on a segment brings up a bubble showing the relevant data.

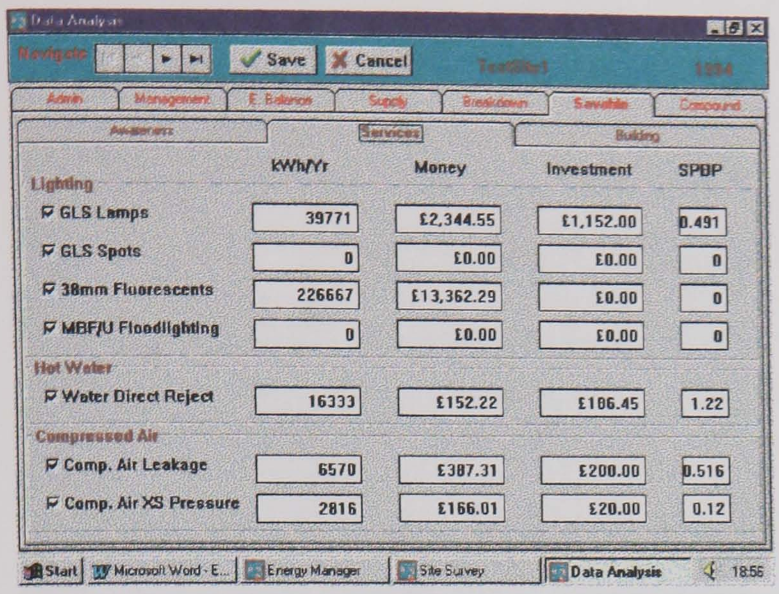


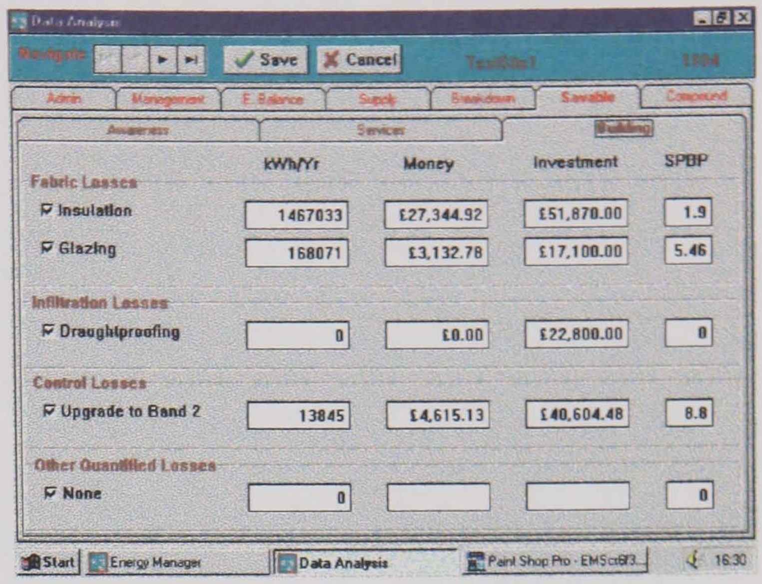
- A pie chart is also automatically generated for the building energy losses.

8.5 The Saveable Pages



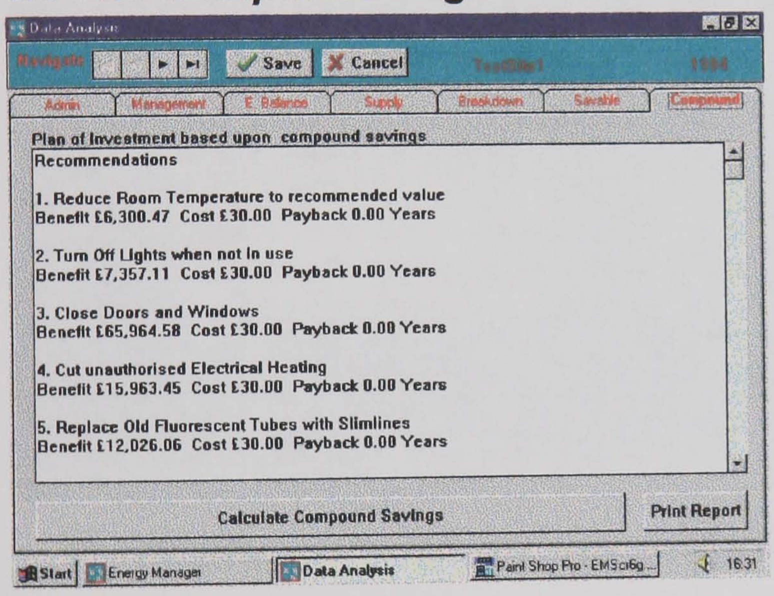
- Individual energy and financial savings possible from improved awareness are automatically quantified.





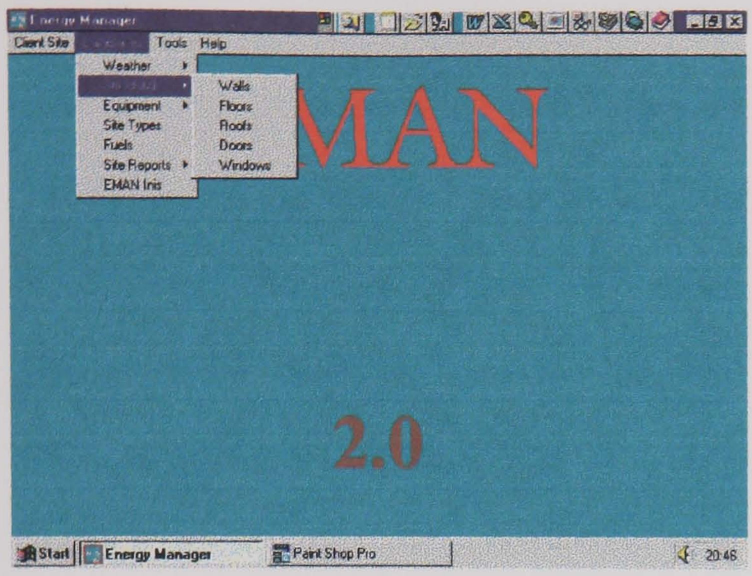
- Energy and financial savings possible from improved services and from structural improvements are automatically quantified, along with estimates of investment costs and simple pay-back periods.

8.6 The Compound Page



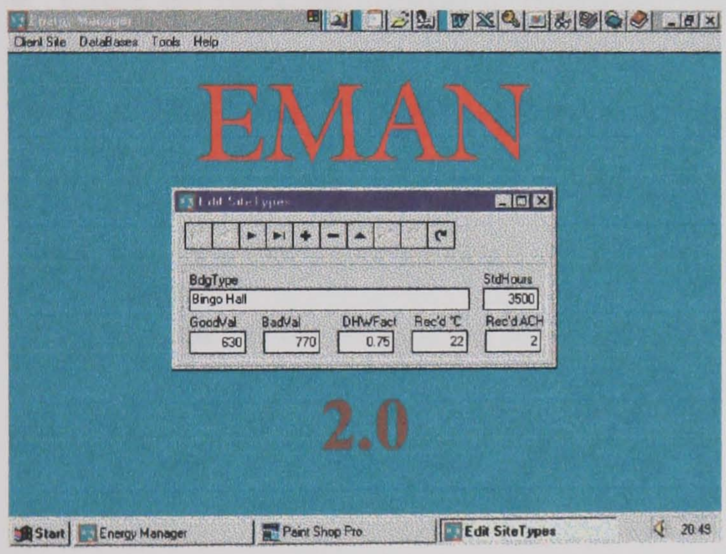
- Click on the Calculate Compound Savings button to generate a list of energy saving recommendations based on the option tick boxes checked on the Saveable pages. These are automatically ranked by pay-back and with compensation for knock on effects.

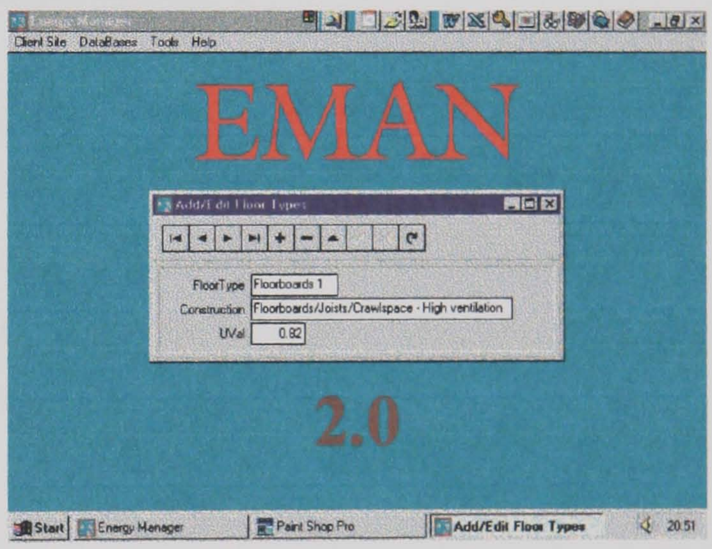
9. The Databases



- Access the databases by the Main Screen menus.

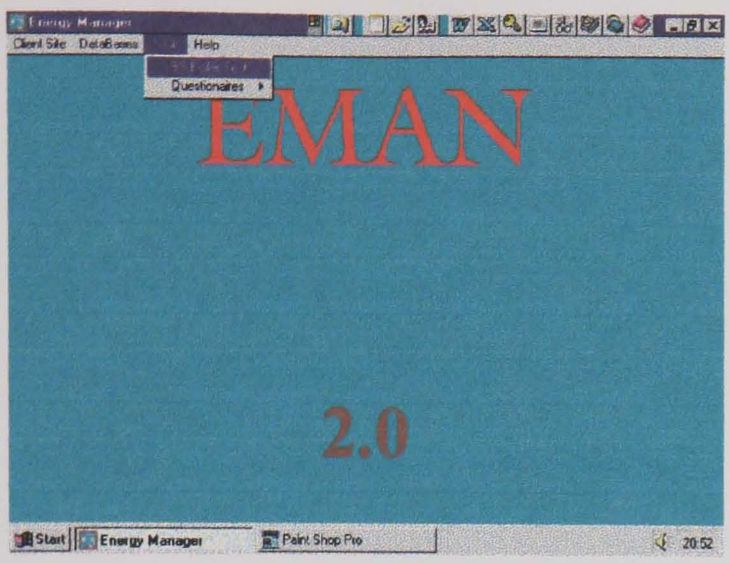
9.1 The Database Edit Screens

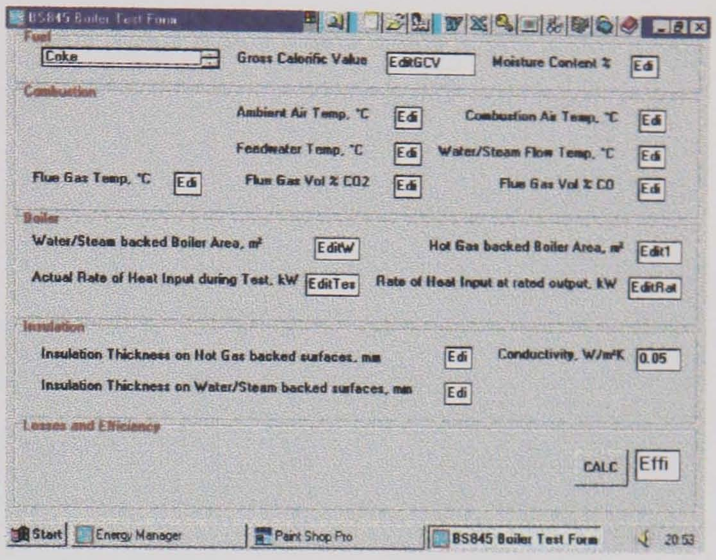




- The Databases can be expanded and edited by the relevant Database Edit Forms.
- Use the navigator bar "+" button to add a new record. Use the arrow buttons to move between existing records.
- Confirm the changes and post them to the Databases by clicking the "✓" button.
- The Databases can also be edited via the Borland Database Desktop, and via other ODBC compliant applications such as spreadsheets and database packages.

10. Tools





- A tool for calculating boiler efficiency is accessible from the Main Screen.
- Enter the relevant information.
- Click on the Calc button to calculate the boiler efficiency.

11. Modification of the programme.

The programme was written in Borland Delphi 1. The source code can be modified, developed further, or cannibalised to produce new programmes. To do this requires Delphi 1 for 16 bit Windows 3.x applications, or later versions of Delphi for 32 bit Windows 95, Windows 98, and Windows NT applications.